Unit 9
Animal Form and Function

Chapter 32: Homeostasis and Endocrine Signaling

Hierarchy

- Cells are organized into
  - **Tissues** = groups of cells with similar appearance and common function
  - **Organs** = different types of tissues organized into functional units
  - **Organ systems** = groups of organs that work together
- Note: The simplest animals, such as sponges, lack organs or even true tissues

4 types of Animal Tissues

1. **Epithelial tissue**
   - Covers the outside of the body and lines organs and cavities
   - Barrier against mechanical injury, pathogens, and fluid loss
2. **Connective tissue**
   - Functions mainly to bind and support other tissues
   - Consists of a few cells scattered through an extracellular matrix
   - Ex: Loose, fibrous, adipose, blood, cartilage, bone

3. Muscle tissue

- Consists of long muscle cells containing actin and myosin that enable muscle to contract
- 3 types
  - **Skeletal muscle** (aka striated muscle)
    - Responsible for voluntary movements
  - **Smooth muscle**
    - Responsible for involuntary activities
  - **Cardiac muscle**
    - Forms contractile wall of the heart
    - Also striated

4. Nervous tissue

- Functions in the receipt, processing, and transmission of information
- **Neurons**
  - Basic units of the nervous system
  - Receives nerve impulses via the *cell body* and multiple extensions called *dendrites*
  - Transmits impulses via extensions called *axons*
- **Glial cells or glia**
  - Support cells
  - Helps nourish, insulate, and replenish neurons

Homeostasis

- Organisms use **homeostasis** to maintain a "steady state" or internal balance regardless of external environment
- In humans, each of the following are maintained at a constant level
  - Body temperature (37℃ or 98.6℉)
  - Blood pH (7.4)
  - Glucose concentration (70-110mg /100mL blood)
- Regulation of room temperature by a thermostat is analogous to homeostasis
- Kidneys excrete salt into urine when dietary salt levels rise

Thermoregulation

- **Thermoregulation** = process by which animals maintain an internal temperature within a tolerable range
- **Endothermic** animals generate heat by metabolism
  - Birds and mammals
- **Ectothermic** animals gain heat from external sources
  - Most invertebrates, fishes, amphibians, and nonavian reptiles
  - May regulate temperature by behavioral means

- Adaptations to enhance thermoregulation
  - Insulation, hair/feathers, layers of fat, raising fur, sweating, shivering, panting,
  - Alter blood (and heat) flow between body core and skin
    - *Vasodilation* is the widening of the diameter of superficial blood vessels
      - Promotes heat loss
    - *Vasoconstriction* is the narrowing of the diameter of superficial blood vessels
      - Reduces heat loss
- Thermoregulation in mammals is controlled by a region of the brain called the **hypothalamus**
  - Functions as a thermostat

Endocrine and Nervous Systems

- **Endocrine system**
  - Signaling molecules are hormones
    - Chemical signals
    - Transported via circulatory system (blood) to specific receptors
  - Coordinates gradual changes that affect entire body
  - Has a domino affect
  - Effects are often long-lasting
- **Nervous system**
  - Neurons transmit signals along dedicated routes
  - Specific
  - Directs immediate and rapid responses

- In vertebrates, the hypothalamus integrates endocrine and nervous systems
- Signals from the hypothalamus travel to the **pituitary gland**
  - Triggers hormone cascade pathway (domino effect)
- The **posterior pituitary** secretes
  - **Oxytocin** = regulates release of milk during nursing in mammals
  - **Antidiuretic hormone** (**ADH**) (aka vasopressin) = maintains blood pressure by retaining water and constricting blood vessels
    - More ADH secreted when dehydrated to conserve water
    - Target cells are in the kidney

- **Epinephrine** is secreted by the adrenal glands
  - Fight or flight response
    - Can raise blood glucose levels
    - Increase blood flow to muscles
    - Decrease blood flow to the digestive system

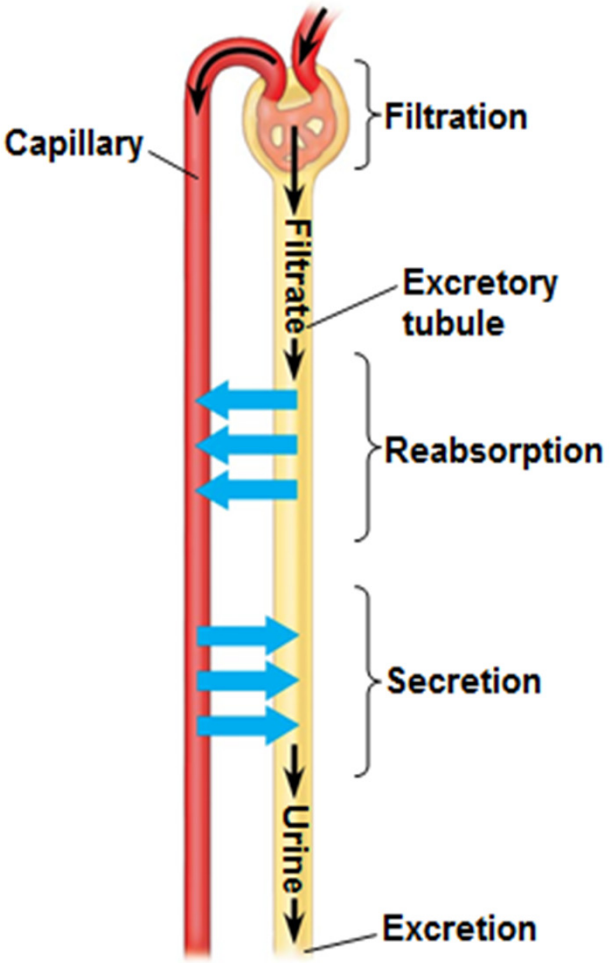
Osmoregulation

- **Osmoregulation** = processes to control solute concentrations and balance water gain/loss
- If two solutions are *isoosmotic*, the movement of water is equal in both directions
- If two solutions differ in osmolarity, the net flow of water is from the hypoosmotic to the hyperosmotic solution
  - *Hyperosmotic* solution has greater concentration of solutes
  - *Hypoosmotic* solution is more dilute

Excretion

- **Excretion** = process that rids the body of waste products
- **Ammonia** (NH_3) excretion is most common in aquatic organisms
- Some animals convert toxic ammonia to less toxic compounds prior to excretion
  - Vertebrates excrete **urea**
  - Insects, land snails, birds, and many reptiles excrete **uric acid** as semisolid paste
    - Less toxic than ammonia and generates very little water loss, but it is energetically more expensive to produce than urea

- Key functions of most excretory systems
  - **Filtration**: Filtering of body fluids
  - **Reabsorption**: Reclaiming valuable solutes
    - Materials are returned to blood from filtrate
  - **Secretion**: Adding nonessential solutes and wastes from the body fluids to the filtrate
    - Selective elimination
  - **Excretion**: Releasing processed filtrate containing nitrogenous wastes from the body



- Flatworms have excretory systems called *protonephridia*
  - Networks of dead-end tubules capped by *flame bulbs* connected to external openings
- In insects and other terrestrial arthropods, *Malpighian tubules* remove nitrogenous wastes from hemolymph without a filtration step
- In vertebrates and some other chordates, the **kidney** functions in both osmoregulation and excretion
  - Functional units of the vertebrate kidney are called **nephrons**

Unit 9
Animal Form and Function

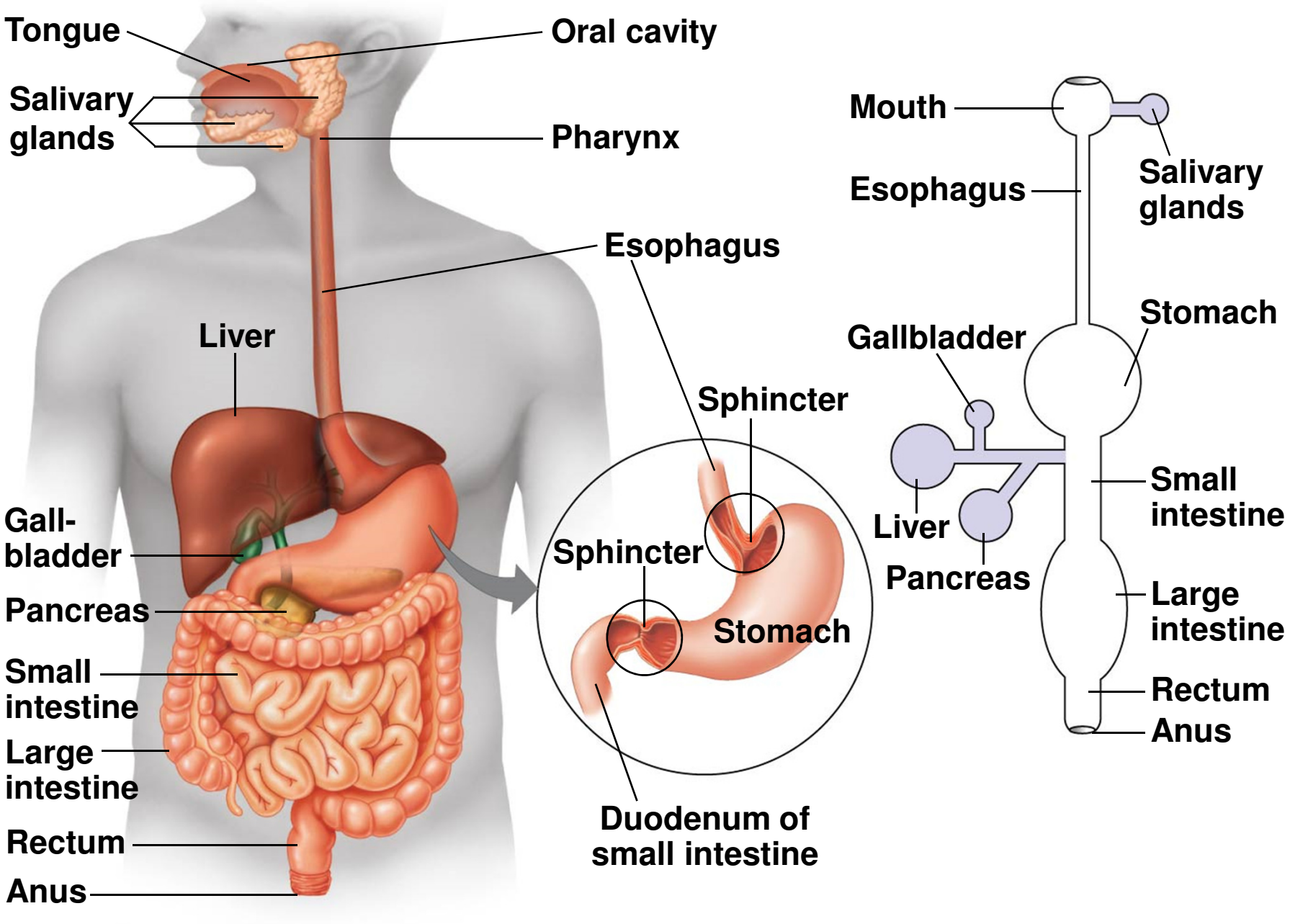
Chapter 33: Animal Nutrition

Digestive System

- Regarding **bile** . . .
  - What is its purpose?
    - Emulsify (digest and absorb) fats in the duodenum of small intestine
  - Where is it produced?
    - Liver
      - Detoxifies
  - Where is it stored?
    - Gallbladder

- Which organ is responsible for . . .
  - The production of insulin and glucagon
    - Pancreas
  - Having a low pH
    - Stomach
  - Absorption due to its high surface area
    - Small intestine
  - Starch digestion
    - Oral cavity (salivary enzyme amylase)
  - Protein digestion
    - Stomach (pepsin in gastric juice)
  - Emulsifying fats
    - Duodenum of small intestine

Figure 33.8


Tongue
Oral cavity
Salivary glands
Pharynx
Esophagus
Liver
Gall-bladder
Pancreas
Small intestine
Large intestine
Rectum
Anus
Sphincter
Sphincter
Stomach
Duodenum of small intestine
Mouth
Esophagus
Salivary glands
Stomach
Gallbladder
Small intestine
Liver
Pancreas
Large intestine
Rectum
Anus

Adaptations

- **Villi** and **microvilli** increase surface area of small intestine
  - Which greatly increases the rate of nutrient absorption
- Shape of teeth reflects diet
- Herbivores
  - Longer alimentary canals
  - Stomachs may have bacteria to digest cellulose
  - Larger **cecums**
    - Part of large intestine that aids in fermentation of plant material

Metabolic Rates

- *Basal metabolic rate, BMR*, is the minimum metabolic rate of a nongrowing endotherm that is at rest, has an empty stomach, and is not experiencing stress
- The metabolic rate of a fasting, nonstressed ectotherm at a particular temperature is called *standard metabolic rate, SMR*
- Endothermy is more energetically costly than ectothermy
  - BMR of endotherms is much higher than SMR of ectotherms!
- For ectotherms and endotherms, activity greatly affects metabolic rate

Glucose Homeostasis

- Insulin and glucagon together maintain glucose levels
  - Regulate synthesis and breakdown of glycogen
- Insulin levels rise after a carbohydrate-rich meal
  - Glucose entering the liver is used to synthesize glycogen
- Between meals, glucose concentration drops
  - Glucagon stimulates the liver to break down glycogen and release glucose into the blood
- The hormones insulin and glucagon are produced in the pancreas
  - *Beta cells* make insulin
    - Released when glucose levels rise
  - *Alpha cells* make glucagon
    - Released when glucose levels drops

Unit 9
Animal Form and Function
Chapter 34: Circulation and Gas Exchange

- Small, nonpolar molecules such as O_2 and CO_2 move between cells and their immediate surroundings by **diffusion**
  - High to low, that's the flow!
    - Passive transport = no energy
  - Diffusion is only efficient over small distances
- In most animals, cells exchange materials with the environment via a fluid-filled **circulatory system**
  - Includes circulatory fluid, vessels, and pump (heart)
- Note: Jellyfish and flatworms lack a circulatory system and instead have **gastrovascular cavities**
  - Function in both digestion and distribution of substances throughout the body

Circulatory Systems

- **Open circulatory system**
  - No distinction between circulatory and interstitial fluid (called **hemolymph)**
  - Found in insects, other arthropods, and some molluscs
  - Less costly in terms of energy expenditure
- **Closed circulatory systems**
  - **Blood** is confined to vessels and is distinct from interstitial fluid
  - Found in annelids, most cephalopods, and all vertebrates
  - One or more hearts pump blood through the vessels
  - Relatively high blood pressure enables effective delivery of O_2 and nutrients to cells of larger and more active animals

Blood Vessels

- The three main types of blood vessels are
  - **Capillaries**
    - Smallest blood vessels and have thin walls
    - Facilitate exchange of substances
  - **Arteries**
    - Carry blood away from heart to various organs
    - Have thicker walls than veins to accommodate high pressure of blood pumped from heart
  - **Veins**
    - Carry blood back to heart
    - Contain valves to maintain unidirectional flow despite low blood pressure here
- Arteries and veins are distinguished by the direction of blood flow (one-way!)
  - Not by O_2 content!

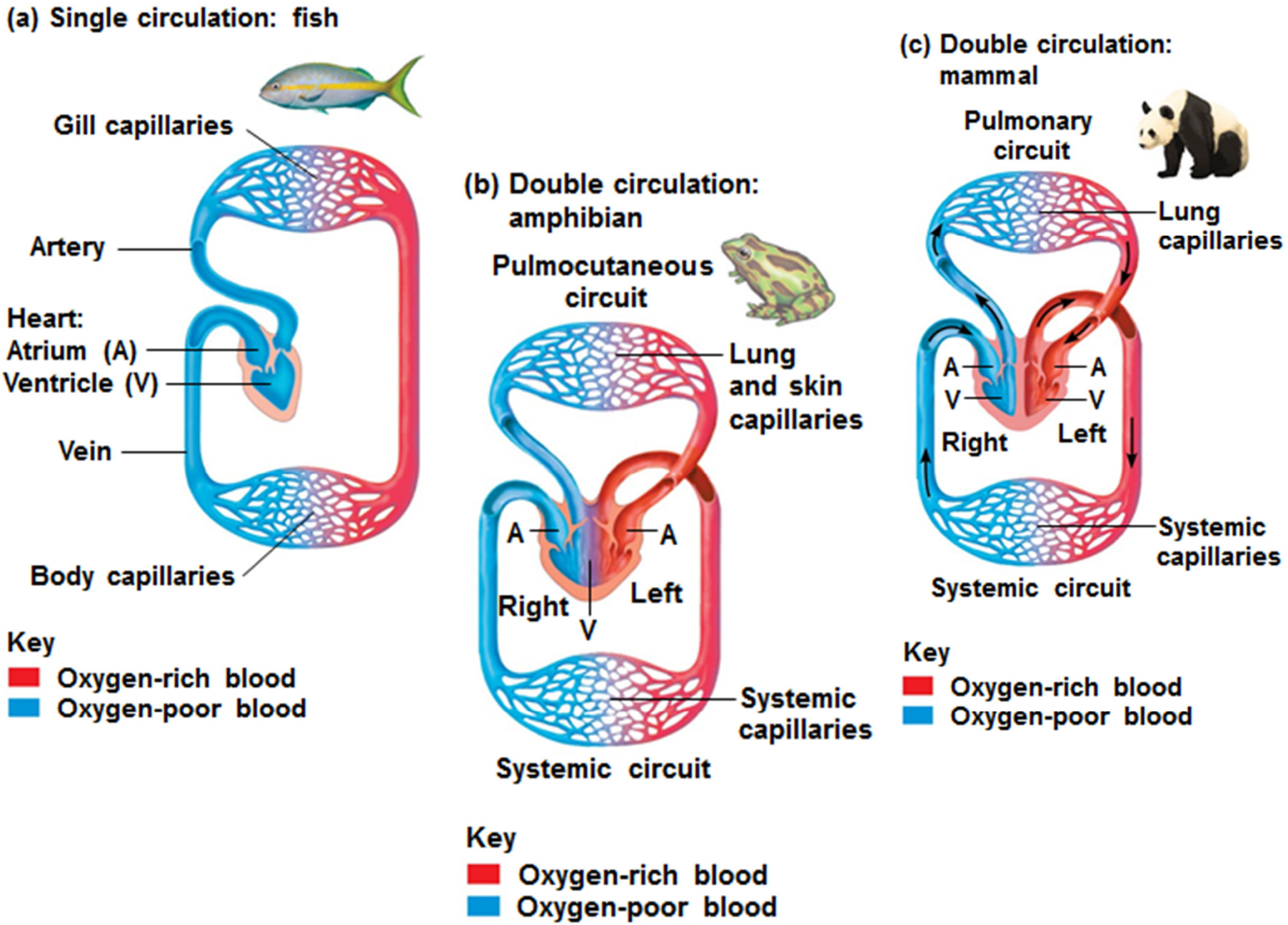
- Vertebrate hearts contain two or more chambers
- Blood enters through an **atrium** and is pumped out through a **ventricle**
  - Fish have a two-chambered heart
  - Amphibians and reptiles have a three-chambered heart
  - Mammals and birds have a four-chambered heart
    - Two atria and two ventricles
    - The left side of the heart pumps and receives only oxygen-rich blood
    - The right side receives and pumps only oxygen-poor blood
- Mammals and birds are endotherms and require more energy and therefore more O_2 than ectotherms

Single vs Double Circulation

- **Single circulation**
  - Blood passes through the heart once in each complete circuit
  - Blood flows directly from respiratory organs to body tissues without first returning to heart
  - Used by bony fishes, rays, and sharks
- **Double circulation**
  - Oxygen-poor and oxygen-rich blood is pumped separately from the right and left sides of the heart
  - Used by amphibians, reptiles, and mammals
  - Maintains higher blood pressure in the organs
  - 2 circuits
    1. Gas exchange circuit
    2. Systemic circuit

- The right side of the heart delivers oxygen-poor blood to capillary beds of the gas exchange tissues via the **gas exchange circuit**
  - Net movement of O_2 into blood and CO_2 out of blood
  - 2 types of gas exchange circuits
    - ***Pulmonary circuit***
      - Capillary beds are all in the lungs
      - Ex: Reptiles and mammals
    - ***Pulmocutaneous circuit***
      - Capillary beds are both the lungs and skin
      - Ex: Amphibians

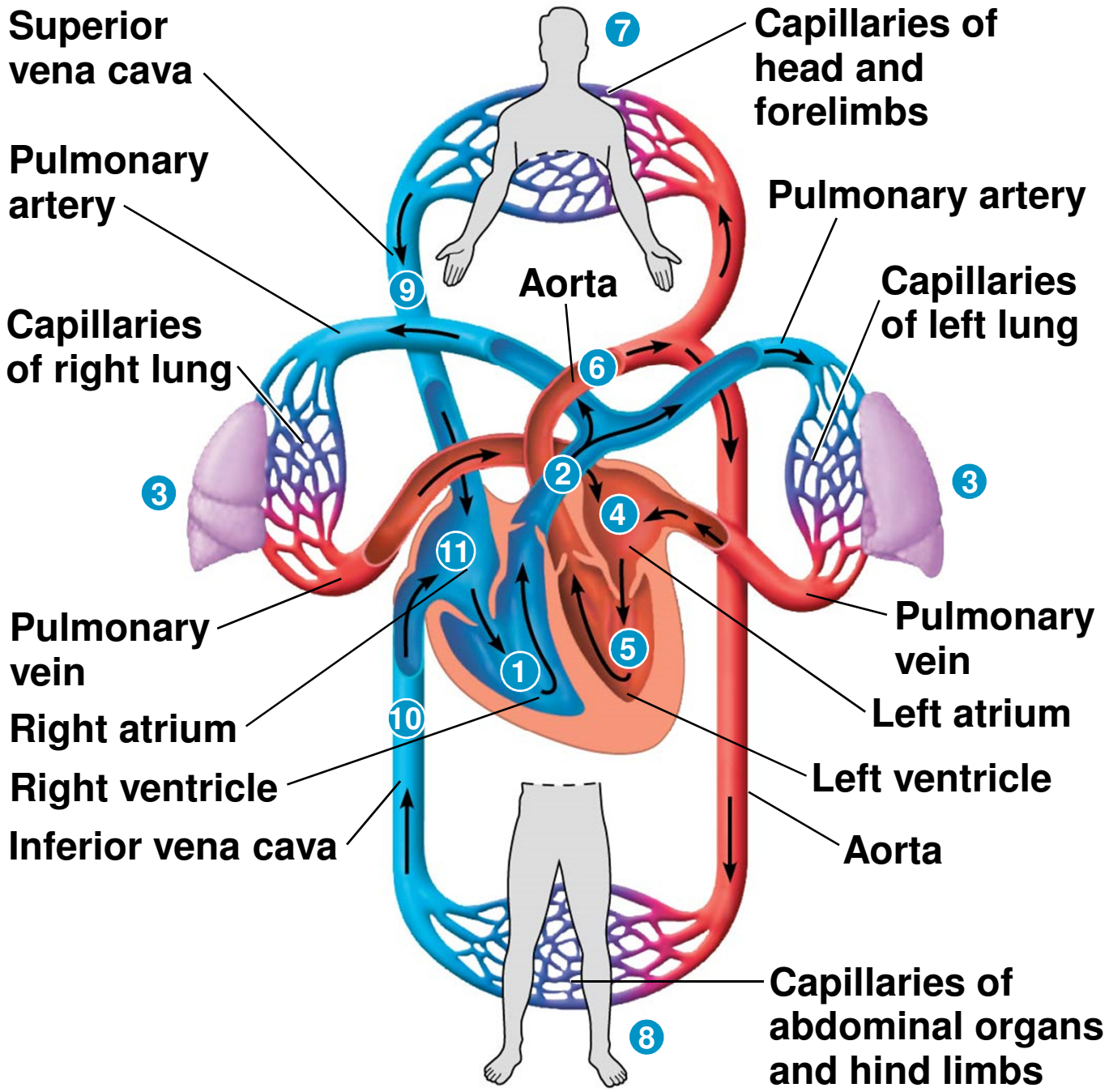
- Oxygenated blood then enters the left side of the heart
  - Blood is propelled to capillary beds and in organs and tissues throughout body
  - O_2, CO_2, nutrients, and wastes are exchanged
  - Oxygen poor blood returns to heart, completing the **systemic circuit**
    - Supplies oxygenated blood to and carries deoxygenated blood away from organs and tissues throughout the body


(a) Single circulation: fish
Gill capillaries
Artery
Heart:
Atrium (A)
Ventricle (V)
Vein
Body capillaries
Key
Oxygen-rich blood
Oxygen-poor blood
(b) Double circulation: amphibian
Pulmocutaneous circuit
Lung and skin capillaries
A
A
Right
Left
V
Systemic capillaries
Systemic circuit
Key
Oxygen-rich blood
Oxygen-poor blood
(c) Double circulation: mammal
Pulmonary circuit
Lung capillaries
A
A
V
V
Right
Left
Systemic capillaries
Systemic circuit
Key
Oxygen-rich blood
Oxygen-poor blood

Mammalian Circulatory System

- Flow of blood in mammalian circulatory system
  - Right ventricle pumps blood to lungs via the pulmonary arteries
    - Picks up O_2, drops off CO_2
  - Oxygen-rich blood travels back to heart via pulmonary veins
  - Blood enters left atrium and flows to left ventricle
  - Blood is pumped to body tissues via the aorta
    - Delivers O_2 and picks up CO_2
  - Oxygen-poor blood travels back to heart via superior and inferior vena cava
  - Blood empties into right atrium and then flows into right ventricle

Figure 34.5


Superior vena cava
Pulmonary artery
Capillaries of right lung
Pulmonary vein
Right atrium
Right ventricle
Inferior vena cava
Capillaries of head and forelimbs
Pulmonary artery
Capillaries of left lung
Aorta
Pulmonary vein
Left atrium
Left ventricle
Aorta
Capillaries of abdominal organs and hind limbs
1
2
3
4
5
6
7
8
9
10
11

- When the heart relaxes, its chambers fill with blood
  - Atria have relatively thin walls and serve as collection chambers for blood returning to the heart
- When the heart contracts, it pumps blood
  - The ventricles are more muscular and contract much more forcefully than the atria
- One complete sequence of pumping and filling is called the **cardiac cycle**
  - Contraction phase is called **systole**
  - Relaxation phase is called **diastole**
- Greatest pressure = systole of ventricle

- Four valves prevent backflow of blood in the heart
  - The **atrioventricular (AV) valves** separate each atrium and ventricle
  - The **semilunar valves** control blood flow to the aorta and the pulmonary artery from the ventricles
- Some cardiac muscle cells can contract without any signal from the nervous system
  - The **sinoatrial (SA) node** initiates atrial contraction
    - AKA- Pacemaker
  - The **atrioventricular (AV) node** initiates ventricular contraction
    - Atria need to completely empty first
  - Signals then travel to Purkinje fibers

Figure 34.6

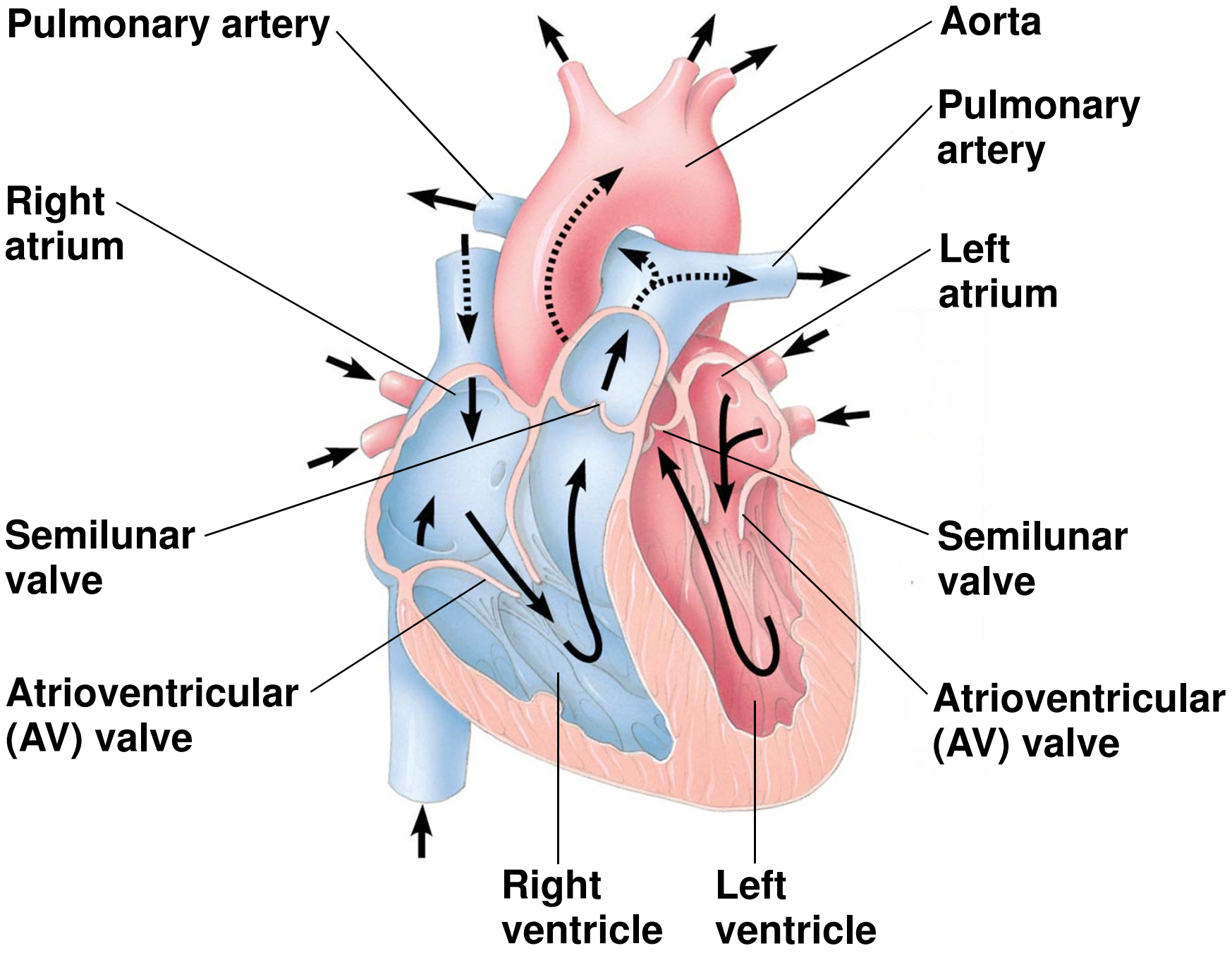
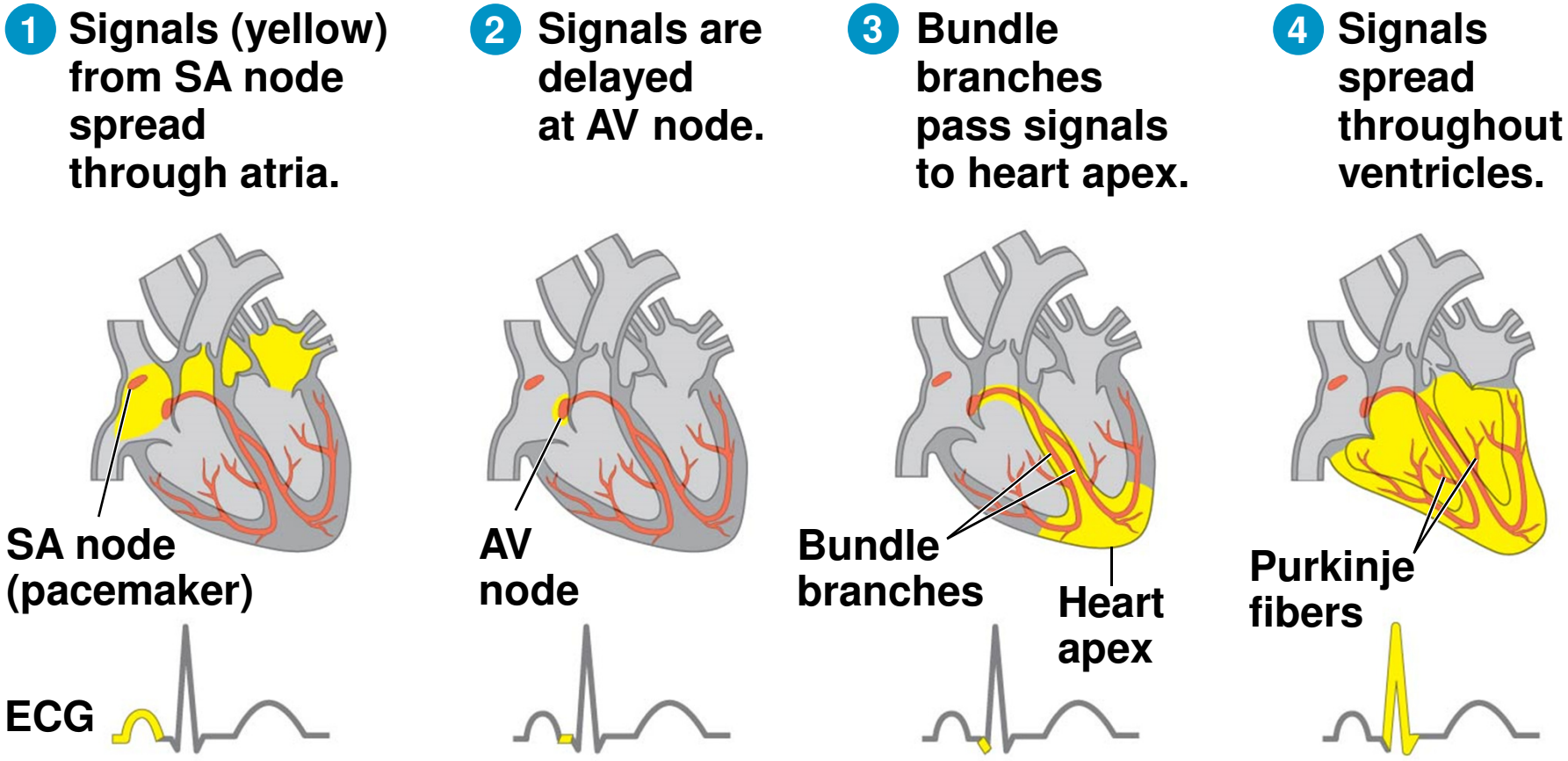

Pulmonary artery
Aorta
Pulmonary artery
Right atrium
Left atrium
Semilunar valve
Semilunar valve
Atrioventricular (AV) valve
Atrioventricular (AV) valve
Right ventricle
Left ventricle

Figure 34.8-4


1 Signals (yellow) from SA node spread through atria.
SA node (pacemaker)
ECG
2 Signals are delayed at AV node.
AV node
3 Bundle branches pass signals to heart apex.
Bundle branches
Heart apex
4 Signals spread throughout ventricles.
Purkinje fibers

- The pacemaker is regulated by two portions of the nervous system
  - Sympathetic division
    - Speeds up the pacemaker
  - Parasympathetic division
    - Slows down the pacemaker
- The pacemaker is also regulated by hormones and temperature
  - Ex: Epinephrine (Fight-or-flight hormone)
    - Causes heart rate to increase

Blood Pressure

- Blood vessel diameter influences blood flow
- **Vasoconstriction** is the contraction of smooth muscle in arteriole walls
  - Increases blood pressure
- **Vasodilation** is the relaxation of smooth muscles in the arterioles
  - Causes blood pressure to fall
- Velocity of blood flow is slowest in the capillary beds
  - Necessary for exchange of materials
- Blood flows from areas of higher pressure to areas of lower pressure
  - Higher in arteries
  - Lower in veins

Blood

- Blood is a connective tissue consisting of cells suspended in a liquid matrix called **plasma**
  - Plasma proteins influence blood pH, osmotic pressure, and viscosity
- Blood contains two classes of cells
  - Red blood cells (**erythrocytes**) transport O_2
    - Their shape increases surface area!
  - White blood cells (**leukocytes**) function in defense
    - Basophils, lymphocytes, eosinophils, neutrophils, monocytes
- **Platelets**, a third cellular element, are fragments of cells that are involved in clotting

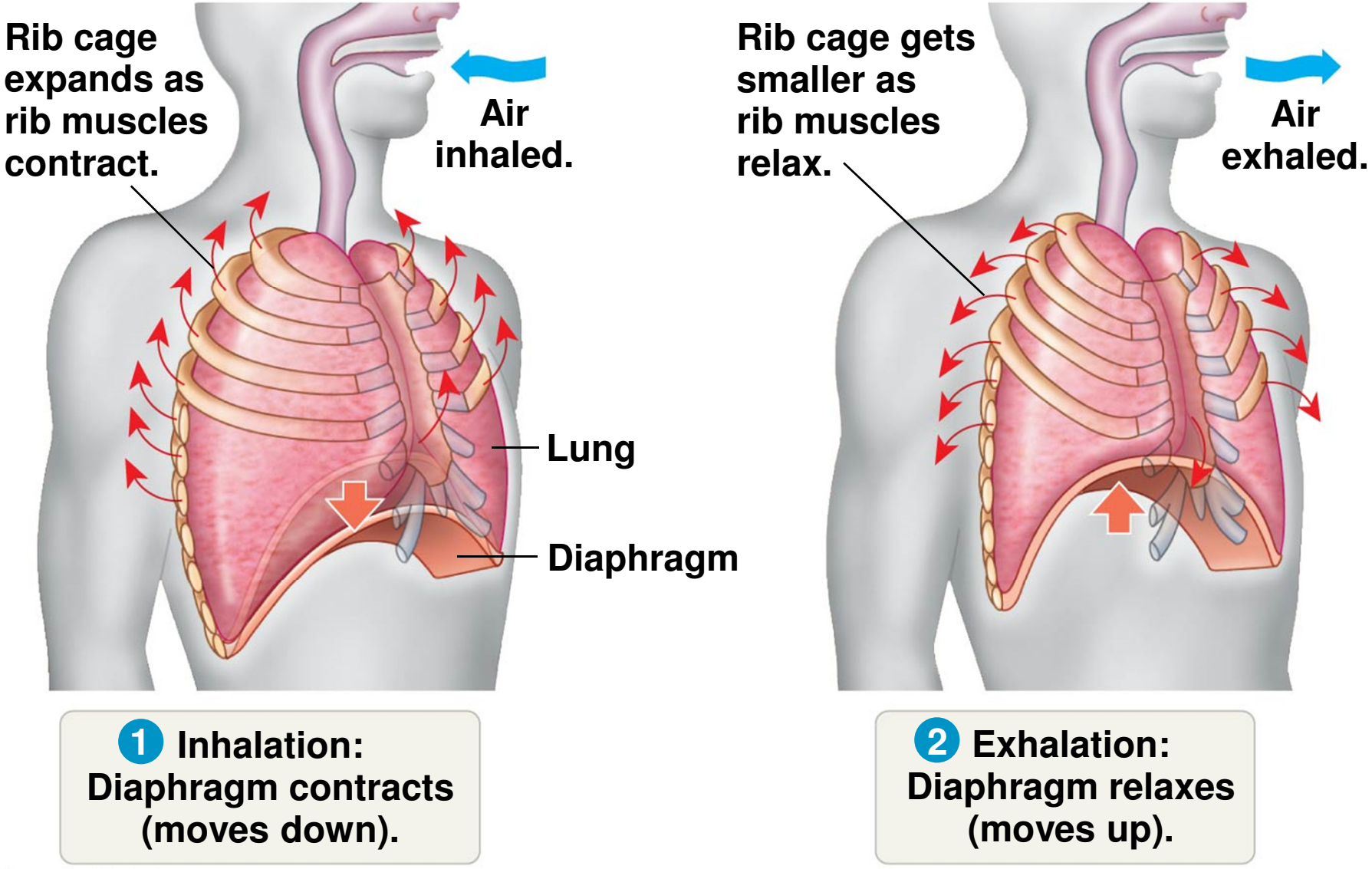
Respiration

- Gas exchange across respiratory surfaces takes place by diffusion
- Respiratory surfaces tend to be large and thin and are always moist
  - Often involve folded or branched organs to increase surface area!
  - Examples:
    - Fish and many other aquatic organisms - Gills
    - Insects - Tracheal system
    - Amphibians, reptiles, birds, mammals – Lungs
- In humans, medulla oblongata controls breathing rate
  - Uses pH as an indicator of blood CO_2 levels

- Mammalian Respiratory System
  - The pharynx directs air to the lungs and food to the stomach
    - Swallowing tips the epiglottis over the glottis in the pharynx to prevent food from entering the **trachea**, or windpipe
  - Air passes through the pharynx, larynx, trachea, bronchi, and bronchioles to the alveoli
  - Gas exchanges occurs in the **alveoli**
    - Increased surface area!

- Mammals ventilate their lungs by **negative pressure breathing**
  - Pulls air into the lungs
  - Contraction and relaxation of **diaphragm** changes volume and pressure in thoracic cavity (and lungs)
- Air moves from high to low pressure
- Diaphragm contracts
  - Volume of cavity/lungs increases
  - Pressure decreases
  - Air moves into lungs
- Diaphragm relaxes
  - Volume of cavity/lungs decreases
  - Pressure increases
  - Air moves out of lungs

Figure 34.22


Rib cage expands as rib muscles contract.
Air inhaled.
Lung
Diaphragm
Rib cage gets smaller as rib muscles relax.
Air exhaled.
1 Inhalation: Diaphragm contracts (moves down).
2 Exhalation: Diaphragm relaxes (moves up).

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Chapter 35: The Immune System

- **Pathogens** are agents that cause disease
  - Ex: Bacteria, fungus, virus, etc
- The **immune system** enables an animal to avoid or limit many infections
  - First line of defense is to help prevent pathogens from gaining entrance to body
  - If the pathogen enters, immune system must distinguish the foreign particles/cells from its own

- All animals have **innate immunity**
  - Active immediately upon infection
  - Present before any exposure to pathogens and is effective from the time of birth
  - Involves nonspecific responses to pathogens
  - Rapid response
  - Consists of external barriers plus internal cellular and chemical defenses
- Vertebrates also have **adaptive immunity**
  - Also known as acquired immunity
  - Develops after exposure to pathogens
  - Very specific response to pathogens
  - Slower response
  - Consists of humoral and cell-mediated responses

Innate Immunity

- Barrier defenses
  - Exoskeleton, skin, mucus, sweat, saliva, tears, etc.
- Phagocytosis
  - **Neutrophils** and eosinophils (white blood cells)
  - **Macrophages** and dendritic cells
- **Natural killer cells**
- Antimicrobial peptides
  - **Interferons** = interfere with viruses
- Inflammatory response
  - **Mast cells** release **histamine** = causes blood vessels to dilate
  - Macrophages and neutrophils release signaling molecule called **cytokines**
  - More blood flow = more antimicrobial peptides

Adaptive Immunity

- Vertebrates have adaptive immunity in addition to innate immunity
  - Pathogen specific!
- The adaptive response relies on two types of **lymphocytes**, or white blood cells
  1. **T cells** = Mature in the **thymus**
  2. **B cells** = Mature in bone marrow
- **Antigens** are foreign substances that can elicit a response from a B or T cell
  - Ex: Bacterial or viral proteins

- When an antigen binds to a B cell receptor
  - B cell gives rise to **plasma cells**
  - Plasma cells secrete **antibodies** (not membrane bound)
    - The antibodies, rather than B cells themselves, defend against pathogens!
- T cells bind only to antigen fragments displayed or presented on a host cell
  - In infected cells, antigens are cleaved into smaller peptides by enzymes
  - **Antigen presentation** = **MHC** molecules bind and transport the antigen fragments to the cell surface
    - Advertises the fact that a host cell contains a foreign substance!
    - Distinguishes self from non-self

- Once activated, a B or T cell undergoes multiple cell divisions to produce a clone of identical cells
  - Called **clonal selection**
- Two types of clones are produced
  - **Effector cells**
    - Act immediately against the antigen
    - Short-lived
    - Effector form of B cells are called **plasma cells**
      - Secrete antibodies
    - Effector form of T cells are
      - Helper T cells
      - Cytotoxic T cells
  - **Memory cells**
    - Can give rise to effector cells if the same antigen is encountered again
    - Long-lived

Immunological Memory

- The first exposure to a specific antigen represents the **primary immune response**
  - Selected B and T cells give rise to their effector forms
- In the **secondary immune response**, memory cells facilitate a faster, stronger, and longer response
  - Occurs if individual is exposed again to same antigen
  - Hallmark of adaptive immunity!

Humoral vs Cell-Mediated Response

- B and T lymphocytes produce a humoral immune response and a cell-mediated immune response
- **Humoral immune response**
  - Antibodies help neutralize or eliminate toxins and pathogens in the blood and lymph
    - Produced by plasma cells (effector form of B cells)
    - Note: Antibodies mark pathogens for destruction
      - They do not kill the pathogens themselves!
- **Cell-mediated immune response**
  - Cytotoxic T cells destroy infected host cells
- Helper T cells interact with both
- Both include a primary and secondary immune response

- **Helper T cells** trigger both the humoral and cell-mediated immune responses
  - Helper T cells themselves do not carry out the responses
  - Helper T cells produce signals that:
    - Activate the appropriate B cells
      - Humoral immunity: Secretion of antibodies by plasma cells
    - Help stimulate cytotoxic T cells
      - Cell mediated immunity: Attack infected cells

Active vs Passive Immunity

- **Active immunity** occurs naturally when a pathogen infects the body
  - Direct exposure to pathogen
  - Make own antibodies
- In **passive immunity**, antibodies in the recipient are produced by another individual
  - Provides immediate, short-term protection
  - Ex: Antibodies cross the placenta from mother to fetus or pass from mother to infant in breast milk
- Both active and passive immunity can be induced artificially
  - Active: vaccines
  - Passive: antivenin

Unit 9
Animal Form and Function

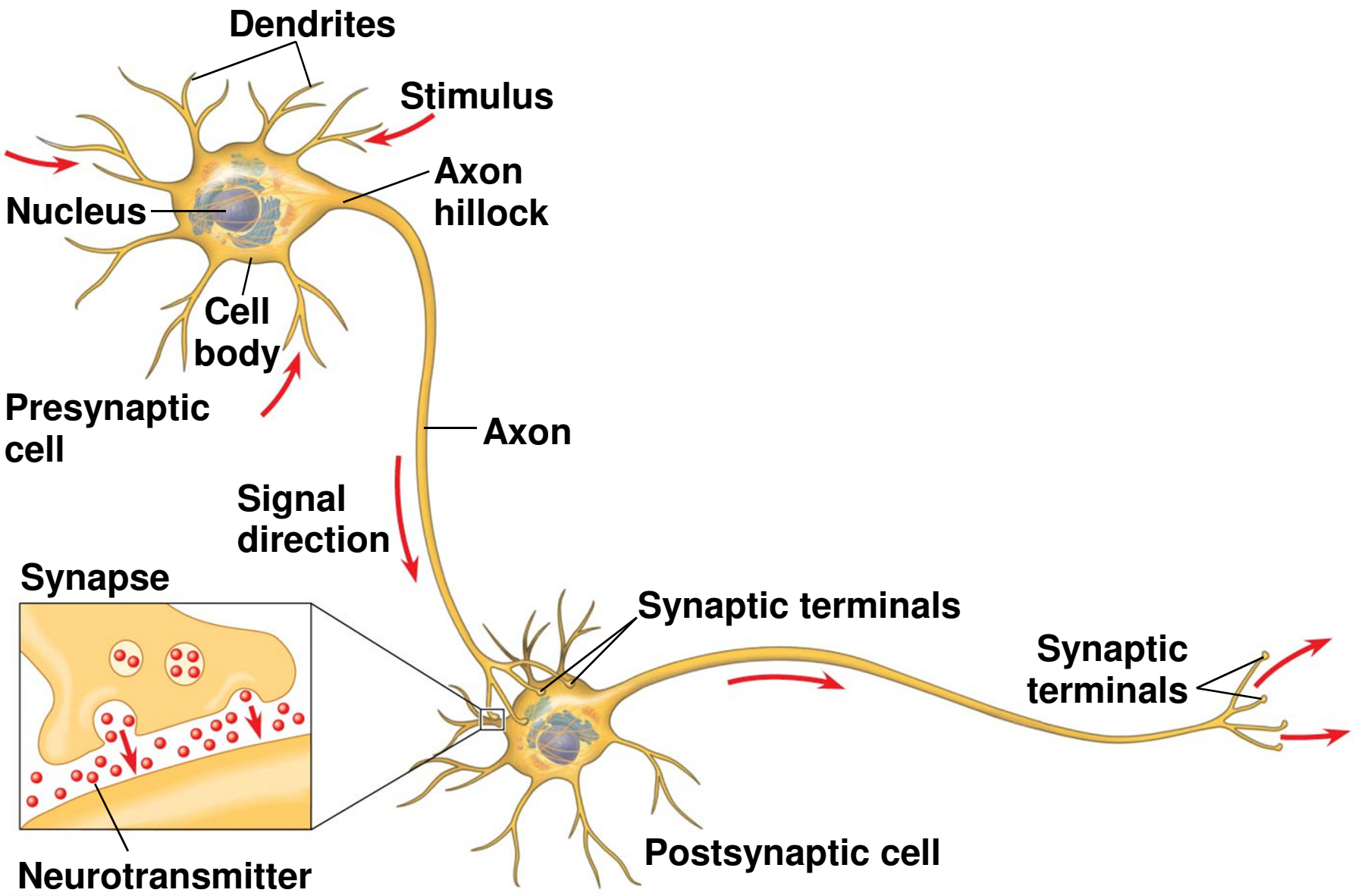
Chapter 37: Neurons, Synapses, and Signaling

Neurons

- **Neurons** are nerve cells that transfer information within the body
- Neurons use two types of signals to communicate:
  - Electrical signals (long distance)
  - Chemical signals (short distance)
- Neurons of vertebrates and most invertebrates require supporting cells called **glial cells**
  - Nourish neurons
  - Insulate axons

- Most of a neuron's organelles are in the **cell body**
- **Dendrites** = highly branched extensions that receive signals from other neurons
- **Axon** = a single, longer extension that transmits signals to other cells
- **Synapse** = Junction between neurons
  - At electrical synapses, the electrical current flows from one neuron to another at gap junctions
  - But most synapses are chemical synapses
    - **Neurotransmitters** = chemical messengers that pass information from the transmitting neuron to the receiving cell at the synapse

Figure 37.2


Dendrites
Stimulus
Axon hillock
Nucleus
Cell body
Presynaptic cell
Axon
Signal direction
Synapse
Synaptic terminals
Synaptic terminals
Postsynaptic cell
Neurotransmitter

- **Sensory neurons** transmit information from eyes and other sensors that detect external stimuli or internal conditions
  - Stimuli include light, sound, touch, smell, blood pressure, muscle tension
- This information is sent to the brain or ganglia, where **interneurons** integrate the information
  - Analyze and interpret
- Neurons that extend out of the processing centers trigger muscle or gland activity
  - For example, **motor neurons** transmit signals to muscle cells, causing them to contract

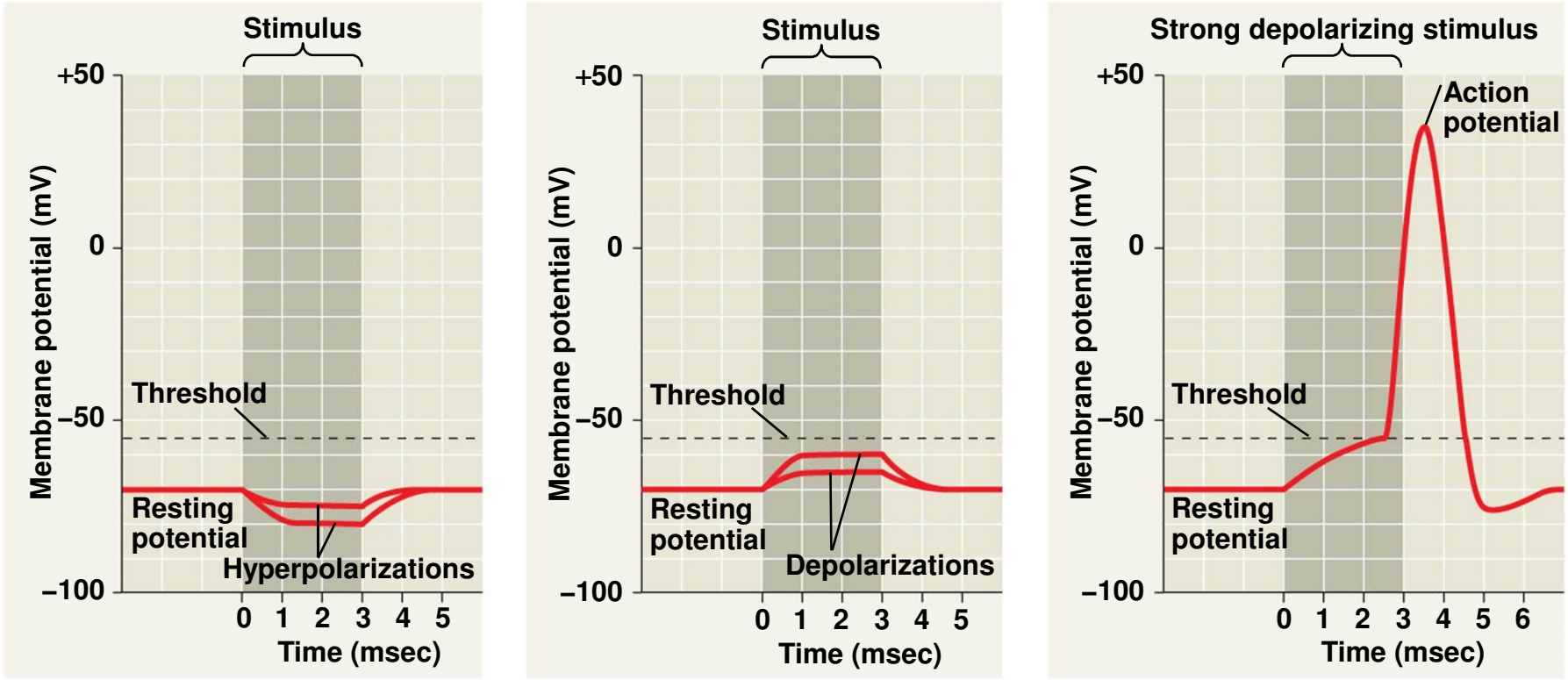
- In many animals, neurons that carry out integration are organized in a **central nervous system (CNS)**
  - Brain and a longitudinal nerve cord
- The neurons that carry information into and out of the CNS form the **peripheral nervous system** (**PNS**)
  - PNS neurons, bundled together, form **nerves**

Membrane and Action Potentials

- The inside of a cell is negatively charged relative to the outside
- In most neurons, the concentration of
  - K^+ is highest inside the cell
  - Na^+ is highest outside the cell
- **Sodium-potassium pumps** use the energy of ATP to maintain these K^+ and Na^+ gradients across the plasma membrane
  - Pumps 3 Na^+ out for every 2 K^+ in
- Changes in membrane potential act as signals, transmitting and processing information

- **Depolarization**
  - Reduction in the magnitude of membrane potential
    - Inside of cell is more positive/less negative
  - Ex: Na^+ diffuses into the cell
- **Hyperpolarization**
  - Increase in magnitude of the membrane potential
    - Inside of cell is more negative/less positive
  - Ex: K^+ diffuses out of cell
- **Action potentials** occur whenever a depolarization increases the membrane potential to a minimum value, called the **threshold**
  - Action potentials are all or none!
  - Have a constant magnitude and transmit signals over long distances

Figure 37.10

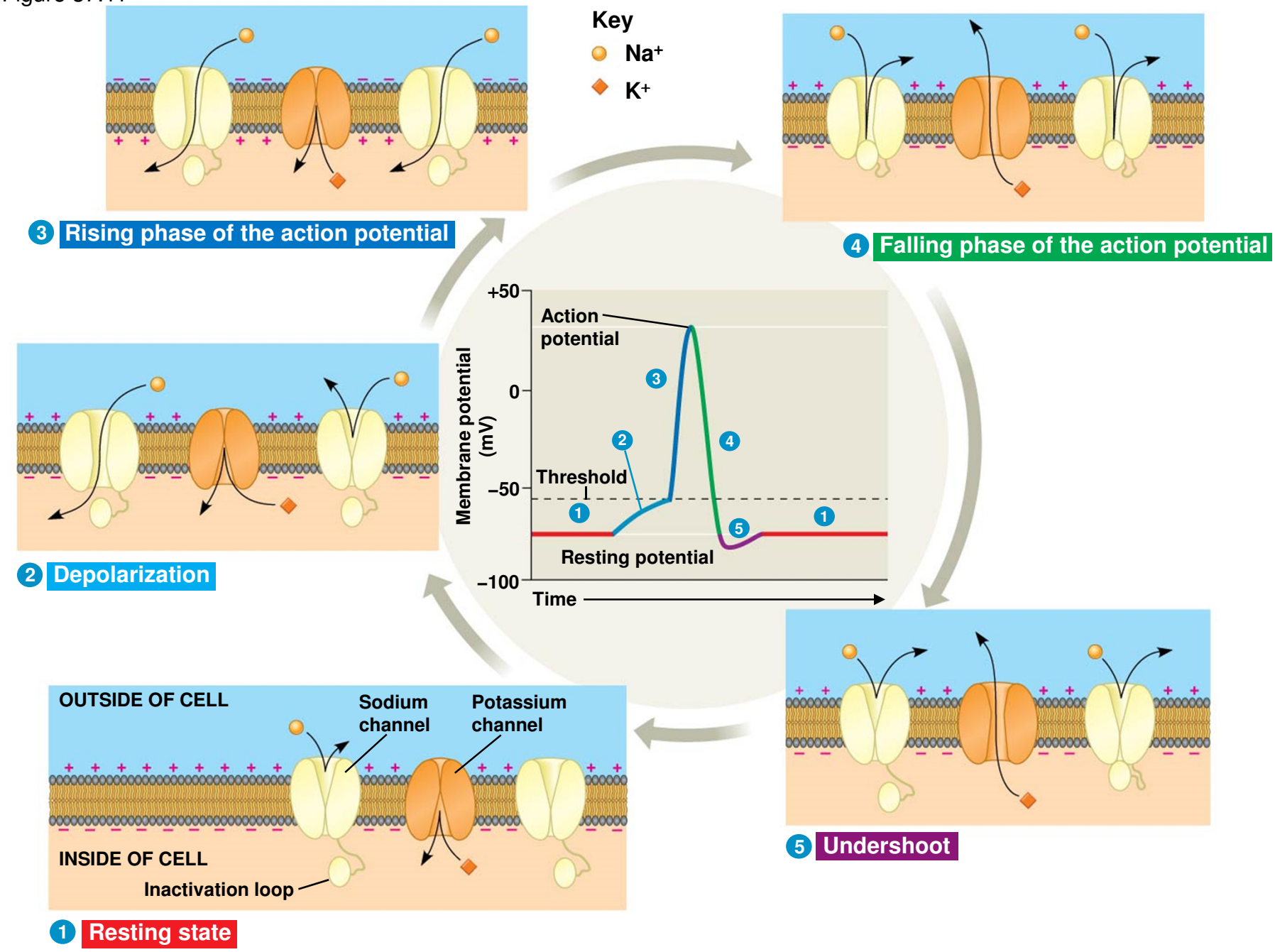


(a) Graded hyperpolarizations produced by two stimuli that increase membrane permeability to K^+

(b) Graded depolarizations produced by two stimuli that increase membrane permeability to Na^+

(c) Action potential triggered by a depolarization that reaches the threshold

Figure 37.11


Key
Na+
K+
3 Rising phase of the action potential
4 Falling phase of the action potential
2 Depolarization
5 Undershoot
1 Resting state
+50
0
−50
−100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
OUTSIDE OF CELL
INSIDE OF CELL
Sodium channel
Potassium channel
Inactivation loop

- During the **refractory period** after an action potential, a second action potential cannot be initiated
  - Result of a temporary inactivation of the Na^+ channels
  - Ensures all signals in an axon travel in one direction
    - From cell body to axon terminals

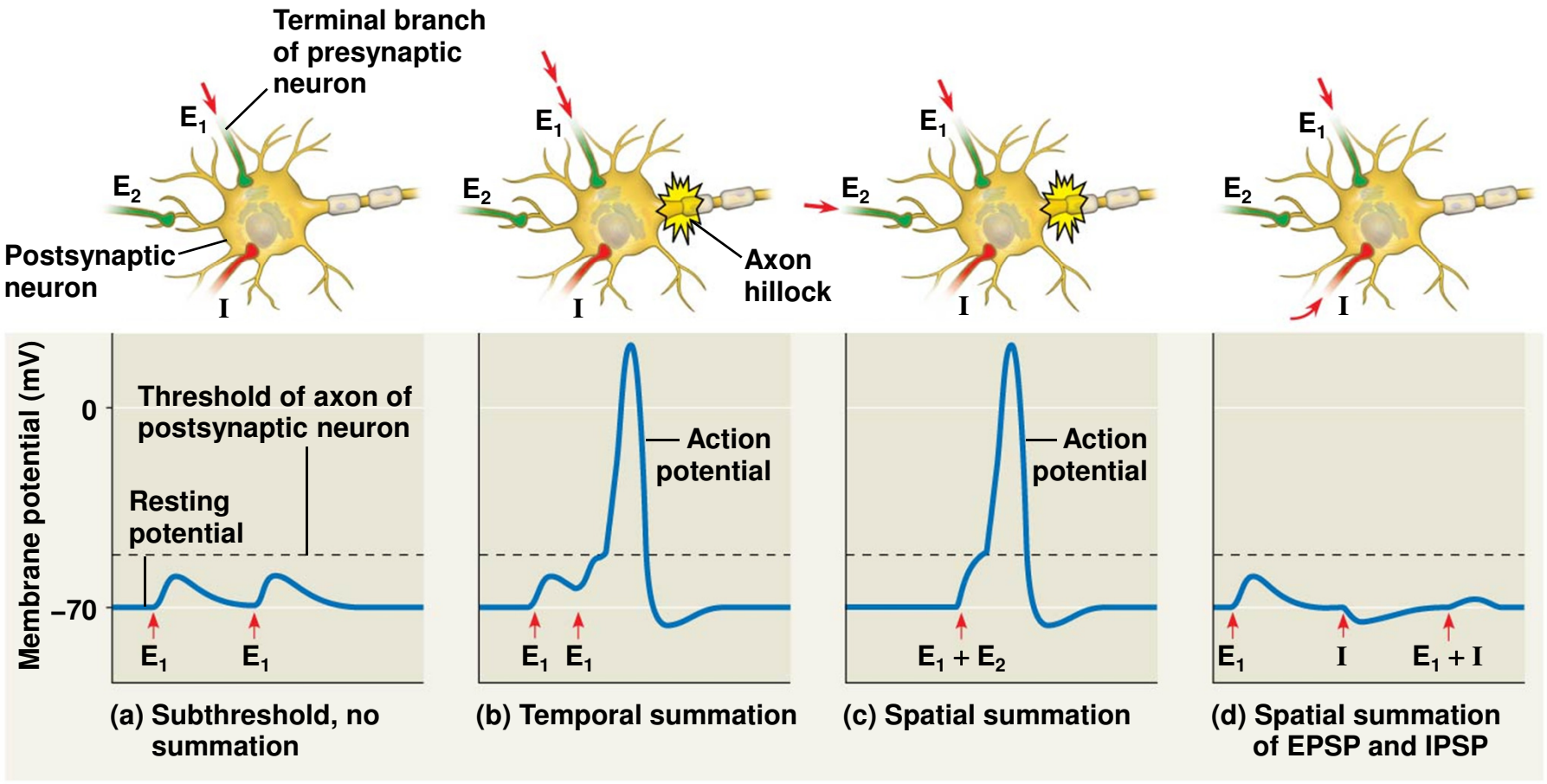
- Wider axons
  - The speed of an action potential increases with the axon's diameter
- Insulation
  - **Myelin sheath** insulates axons in vertebrates
    - Enables fast conduction of action potentials
  - Myelin sheaths are produced by two types of glia:
    - **Oligodendrocytes** in the CNS
    - **Schwann cells** in the PNS
- Faster action potentials = thick, myelinated axons
- Slower action potentials = thin, non-insulated axons
- Action potentials are formed only at **nodes of Ranvier**
  - Gaps in the myelin sheath where voltage-gated Na^+ channels are found

Postsynaptic Potentials

- Direct synaptic transmission involves binding of neurotransmitters to **ligand-gated ion channels** in the postsynaptic cell
- Neurotransmitter binding causes ion channels to open, generating a postsynaptic potential
- Postsynaptic potentials fall into two categories
  - **Excitatory postsynaptic potentials (EPSPs)**
    - Depolarizations that bring the membrane potential toward threshold
    - More permeable to Na+
  - **Inhibitory postsynaptic potentials (IPSPs)**
    - Hyperpolarizations that move the membrane potential farther from threshold
    - More permeable to K+

- In summation, postsynaptic potentials are added together
  - **Temporal summation**
    - Two postsynaptic potentials are produced in rapid succession
      - Same dendrite, slightly different time
  - **Spatial summation**
    - Postsynaptic potentials produced nearly simultaneously by different synapses on the same postsynaptic neuron
      - Same time, different dendrites
- More IPSPs = more negative
  - Hyperpolarization
- More EPSPs = more positive
  - Depolarization

Figure 37.17


Terminal branch of presynaptic neuron
E1
E2
Postsynaptic neuron
I
Axon hillock
Membrane potential (mV)
0
–70
Threshold of axon of postsynaptic neuron
Resting potential
Action potential
(a) Subthreshold, no summation
(b) Temporal summation
(c) Spatial summation
(d) Spatial summation of EPSP and IPSP

Neurotransmitters

- **Acetylcholine** = important in muscle stimulation
- **Gamma-aminobutyric acid (GABA)** = inhibitory neurotransmitter
- **Norepinephrine** and **epinephrine** = excitatory neurotransmitters in the autonomic nervous system (involuntary)
- **Dopamine** and **serotonin** = affect sleep, mood, attention, learning
- **Endorphins** = decrease our perception of pain

Unit 9
Animal Form and Function

Chapter 38: Nervous and Sensory Systems

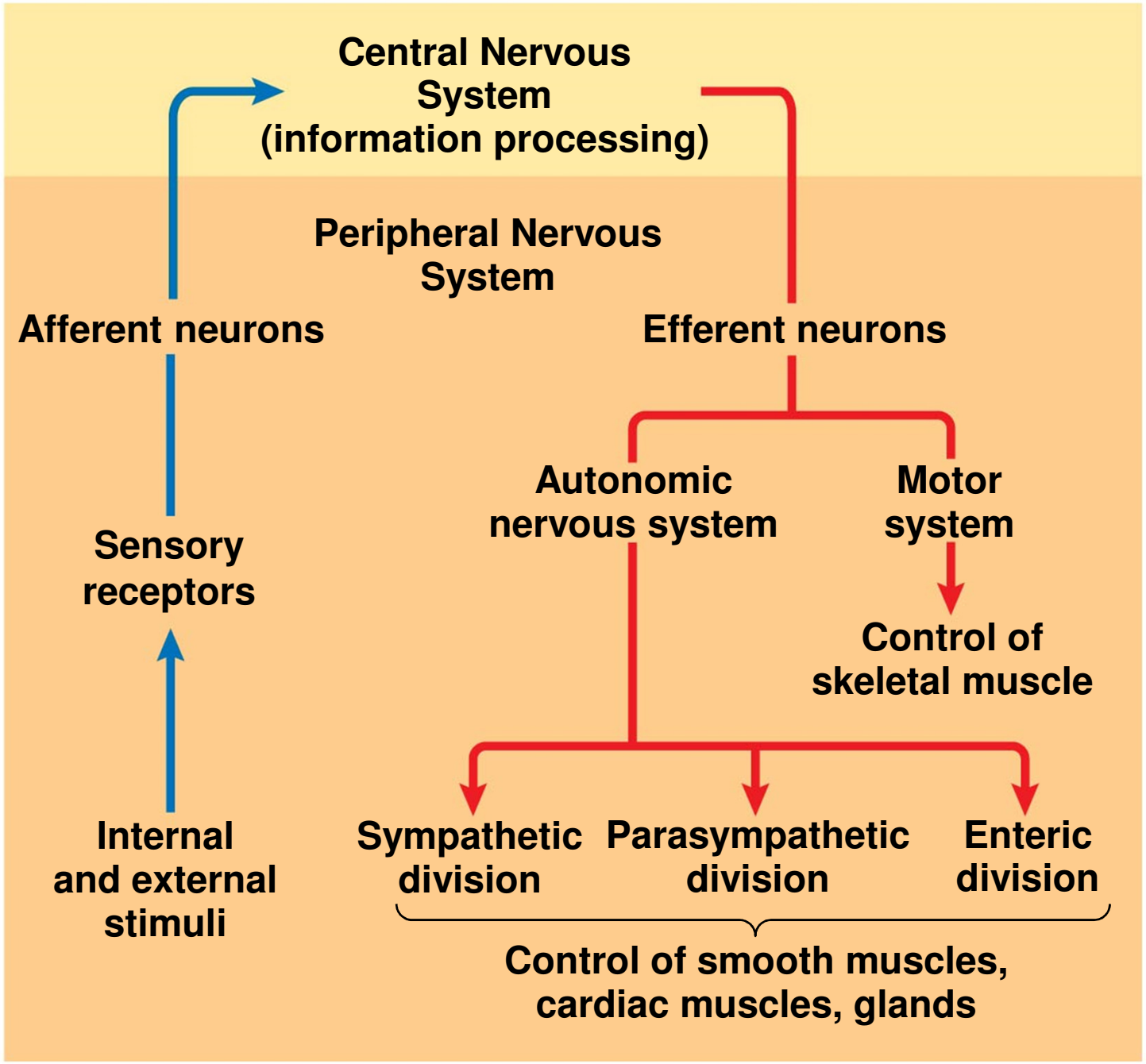
- The brain and spinal cord contain
  - **Gray matter**, which consists mainly of neuron cell bodies and glia
  - **White matter**, which consists of bundles of myelinated axons
    - Makes up outer layer in spinal cord
      - Links CNS to PNS
    - Located in interior of brain
      - Signaling functions in learning, emotions, processing sensory info, and generating commands

The Peripheral Nervous System

- The PNS transmits information to and from the CNS
- **Afferent** neurons transmit information to CNS
  - Sensory
- **Efferent** neurons transmit information away from CNS
  - The PNS has two efferent components:
    - The **motor system** carries signals to skeletal muscles
      - Can be voluntary or involuntary (reflexes)
    - The **autonomic nervous system** regulates smooth and cardiac muscles
      - Generally involuntary

- The autonomic nervous system has 3 divisions:
  - The **enteric division** controls activity of the digestive tract, pancreas, and gallbladder
  - The **sympathetic division** regulates the "fight-or-flight" response
  - The **parasympathetic division** generates opposite responses in target organs and promotes calming and a return to "rest and digest" functions
- Note:
  - Sympathetic and parasympathetic are antagonistic
  - Enteric and parasympathetic are similar

Figure 38.5


Central Nervous System (information processing)
Peripheral Nervous System
Afferent neurons
Efferent neurons
Sensory receptors
Autonomic nervous system
Motor system
Control of skeletal muscle
Internal and external stimuli
Sympathetic division
Parasympathetic division
Enteric division
Control of smooth muscles, cardiac muscles, glands

Human Brain

- **Cerebrum**
  - Dorsal portion of vertebrate forebrain
  - Controls skeletal muscle contraction
    - Motor cortex
  - Integrating center for learning, emotion, memory, and perception
    - Calculation, contemplation, and cognition
  - Surface of cerebrum is called the **cerebral cortex**
    - Vital for perception, voluntary movement, and learning
    - Cognitive functions mainly reside here

- Cerebrum is divided into 2 hemispheres
  - Left side receives info from and controls movement of right side of body and vice versa
  - **Corpus callosum** connects them, enabling them to process info together

- Four regions, or *lobes*
  - Frontal
    - Decision making, reasoning, cognition,
    - Motor skills
  - Temporal - Auditory
  - Occipital - Visual
  - Parietal - Tactile

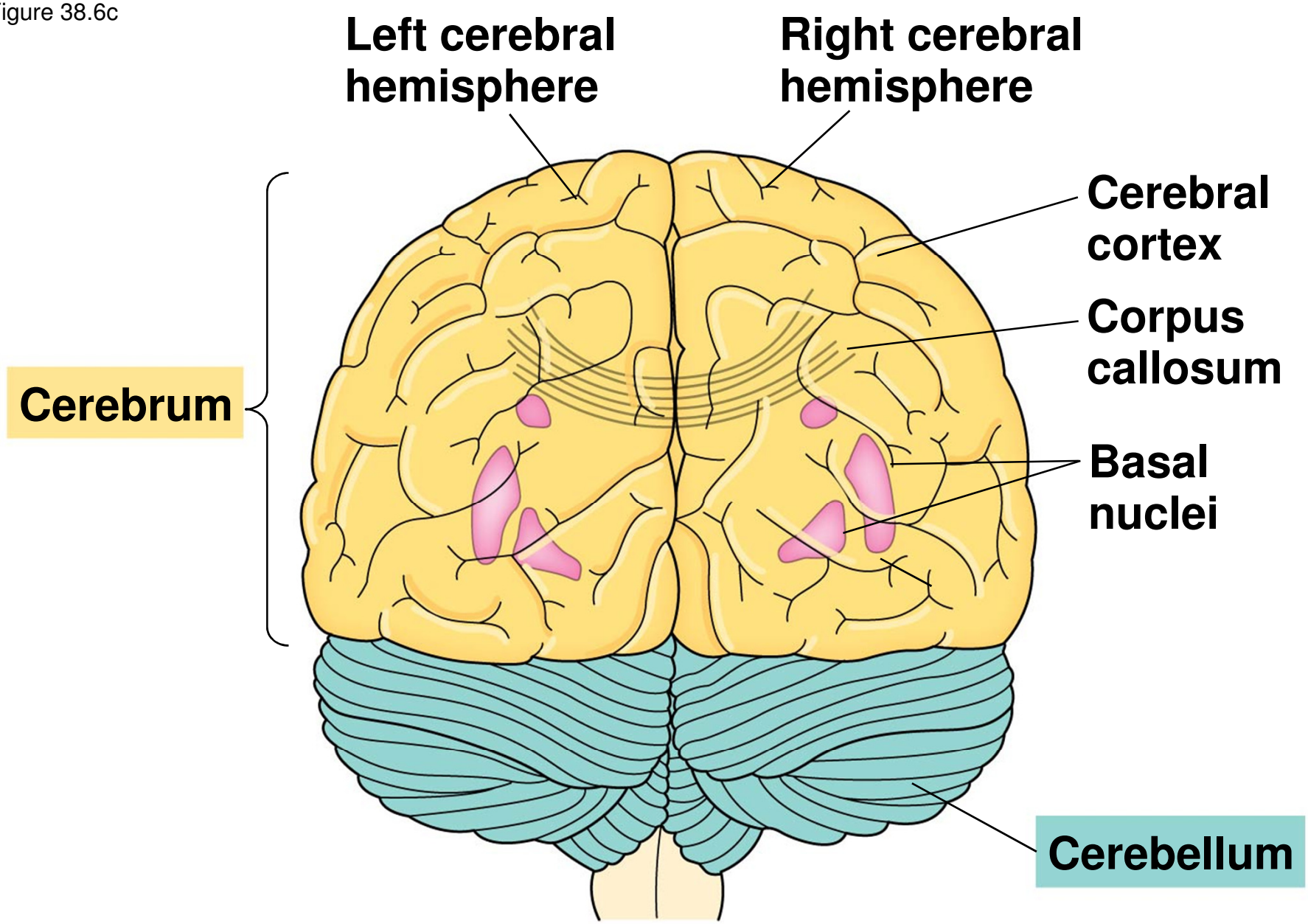
- *Broca's area* is active when speech is generated
  - In left frontal lobe
- *Wernicke's area* is active when speech is heard
  - In posterior of the left temporal lobe

- **Cerebellum**
  - Part of vertebrate hindbrain
    - Located dorsally
  - Coordinates movement and balance
    - Hand-eye coordination
  - Helps in learning and remembering motor skills

- **Diencephalon** gives rise to
  - **Thalamus**
    - Main input center for sensory info going to cerebrum
  - **Hypothalamus**
    - Think homeostasis!
      - Functions as thermostat
    - Central biological clock
    - Regulates pituitary gland
      - Regulates hunger and thirst
      - Plays a role in mating behaviors
      - Initiates fight-or-flight response
  - Epithalamus
    - Includes pineal gland (source of melatonin)

- **Brainstem** consists of
  - Midbrain
    - Relay station for info traveling between PNS and cerebrum
    - Coordinates hearing and visual reflexes
  - **Pons**
    - Regulates sleep and arousal
  - **Medulla oblongata**
    - Controls several automatic, homeostatic functions
      - Breathing
      - Heart rate and blood vessel activity
      - Swallowing, vomiting, digestion

Figure 38.6c



Adult brain viewed from the rear

Figure 38.6d

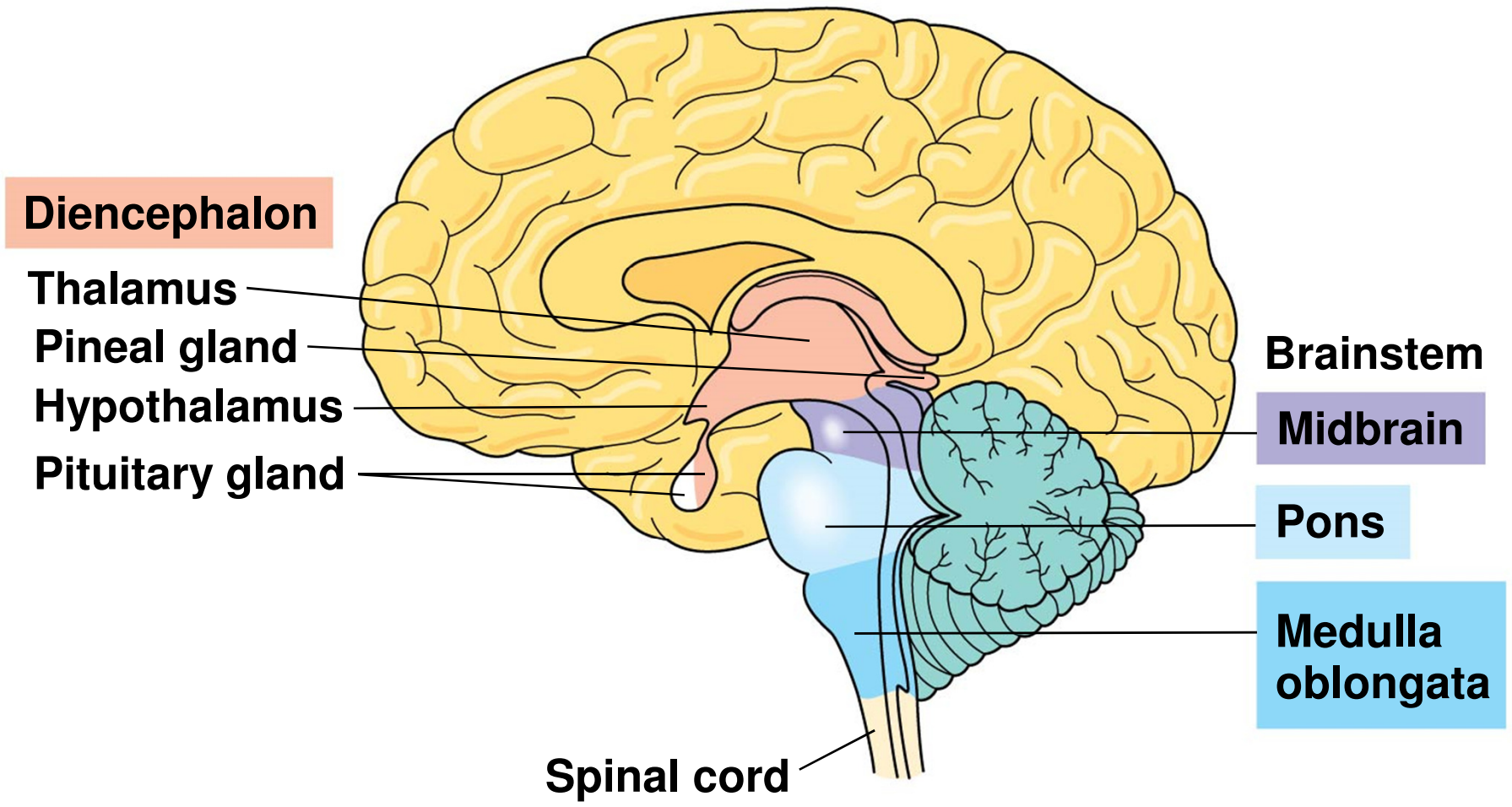
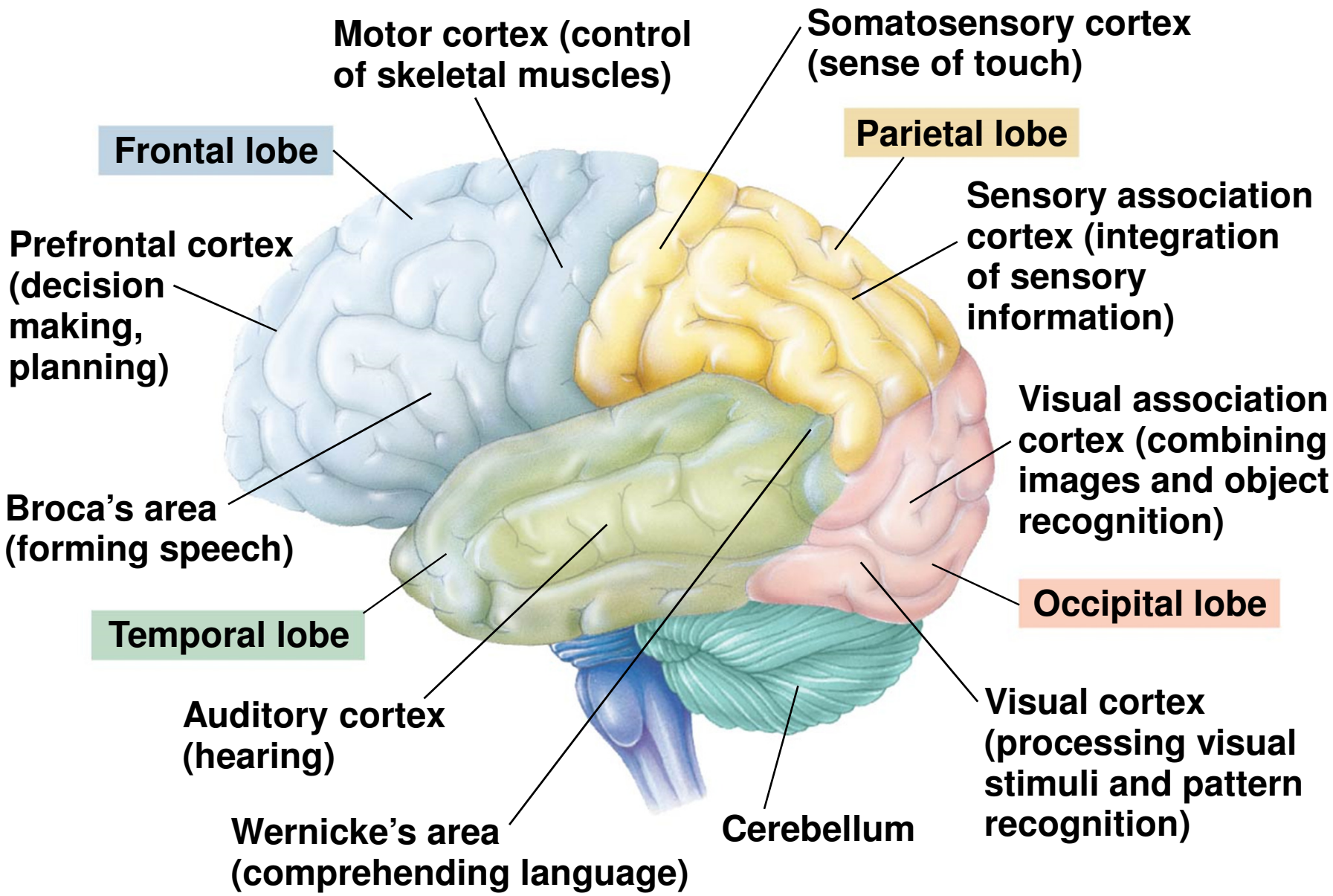

Diencephalon
Thalamus
Pineal gland
Hypothalamus
Pituitary gland
Brainstem
Midbrain
Pons
Medulla oblongata
Spinal cord

Figure 38.11


Motor cortex (control of skeletal muscles)
Somatosensory cortex (sense of touch)
Frontal lobe
Parietal lobe
Prefrontal cortex (decision making, planning)
Sensory association cortex (integration of sensory information)
Visual association cortex (combining images and object recognition)
Broca's area (forming speech)
Occipital lobe
Temporal lobe
Auditory cortex (hearing)
Visual cortex (processing visual stimuli and pattern recognition)
Wernicke's area (comprehending language)
Cerebellum

- *Limbic system* = generation and experience of emotions
  - Includes amygdala, hippocampus, and parts of the thalamus
    - *Amygdala* = most important for emotional memory
- We hold information for a time in **short-term memory** and then release it if it becomes irrelevant
  - Accessed via the *hippocampus*
- **Long-term memory** is activated when we hold, associate, and recall information
  - Links in the hippocampus are replaced by connections within the cerebral cortex itself

Sensory Reception and Transduction

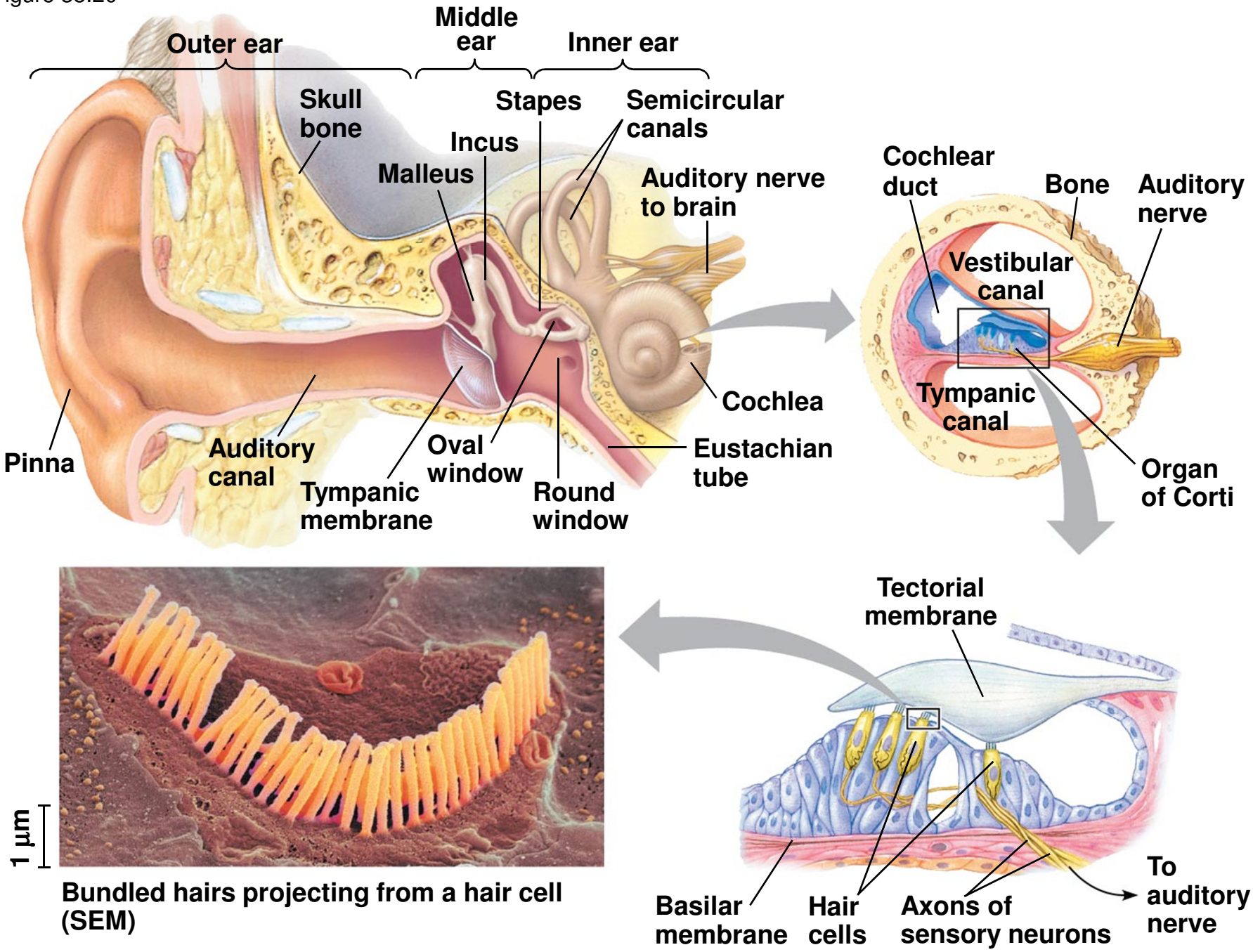
- A sensory pathway begins with **sensory reception**
  - Detection of stimuli by **sensory receptors**
    - Mechanoreceptors = sense pressure, touch, motion, sound
    - Electromagnetic receptors = detect light
    - Thermoreceptors = detect heat
    - Nociceptors = pain receptors
    - Chemoreceptors = odors and tastes
- **Sensory transduction** is the conversion of stimulus energy into a change in the membrane potential of a sensory receptor
  - Transmitted as action potential

Hearing and Equilibrium

- Hearing and perception of body equilibrium are related in most animals
- Equilibrium
  - Most invertebrates maintain equilibrium using mechanoreceptors located in organs called **statocysts**
  - Terrestrial vertebrates – ear
    - The **utricle** and **saccule** contain granules called otoliths that allow us to perceive position
    - Three **semicircular canals** contain fluid and can detect angular movement in any direction
    - **Eustachian tube** equalizes pressure between middle ear and atmosphere

- Hearing
  - The **tympanic membrane** (eardrum) vibrates in response to vibrations in air
  - Three bones of the middle ear create pressure waves in fluid of cochlea
    - Malleus (hammer)
    - Incus (anvil)
    - Stapes (stirrup)
  - **Cochlea** contain **hair cells** in **organ of Corti** that vibrate in response

Figure 38.20

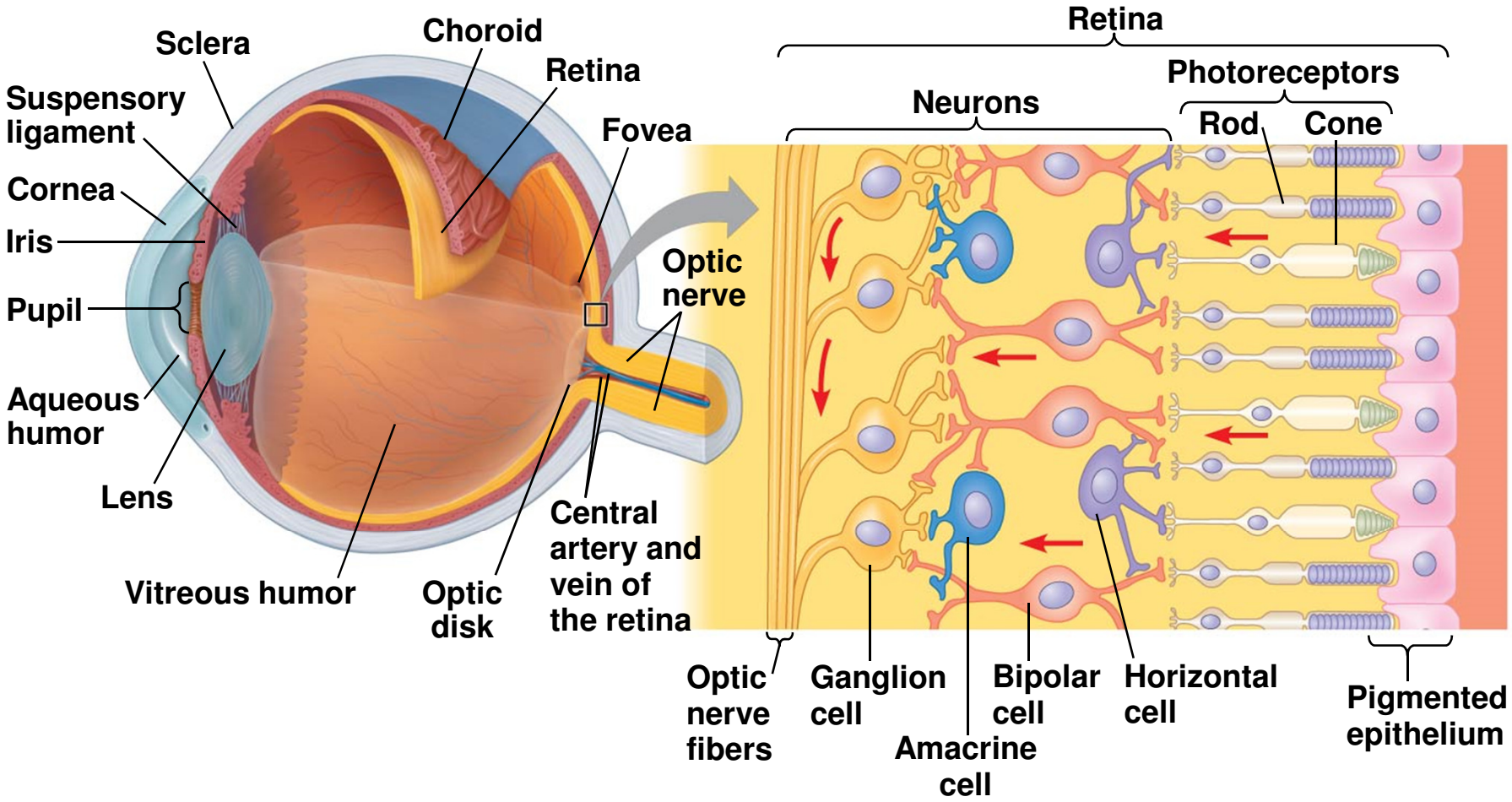

Outer ear
Middle ear
Inner ear
Skull bone
Stapes
Semicircular canals
Incus
Malleus
Auditory nerve to brain
Cochlear duct
Bone
Auditory nerve
Vestibular canal
Tympanic canal
Organ of Corti
Cochlea
Pinna
Auditory canal
Tympanic membrane
Oval window
Round window
Eustachian tube
1 µm
Bundled hairs projecting from a hair cell (SEM)
Tectorial membrane
Basilar membrane
Hair cells
Axons of sensory neurons
To auditory nerve

Vision

- Light detectors all contain **photoreceptors**
  - Cells that contain light-absorbing pigment molecules
- Planarians have a pair of eyespots located near the head
- Insects and crustaceans have **compound eyes**
  - Effective at detecting movement
- Vertebrates have **single-lens eyes**
  - Some focus by moving lens forward or backwards
  - Others, like mammals, change the shape of lens
  - Note: It is the brain that “sees”

- Single-lens eyes work on a camera-like principle
  - **Pupil** is the small opening in the eye through which light can enter
  - **Iris** expands or contracts, changing the diameter of the pupil to control how much light enters
  - A single **lens** focuses light on a layer of photoreceptors located in the **retina**
    - **Rods** are more sensitive to light but do not distinguish colors
    - **Cones** produce color vision but are less sensitive
  - The **fovea** is the center of the visual field
    - Contains no rods but has a high density of cones

Figure 38.25a



Unit 9
Animal Form and Function

Chapter 39:

Motor Mechanisms and Behavior

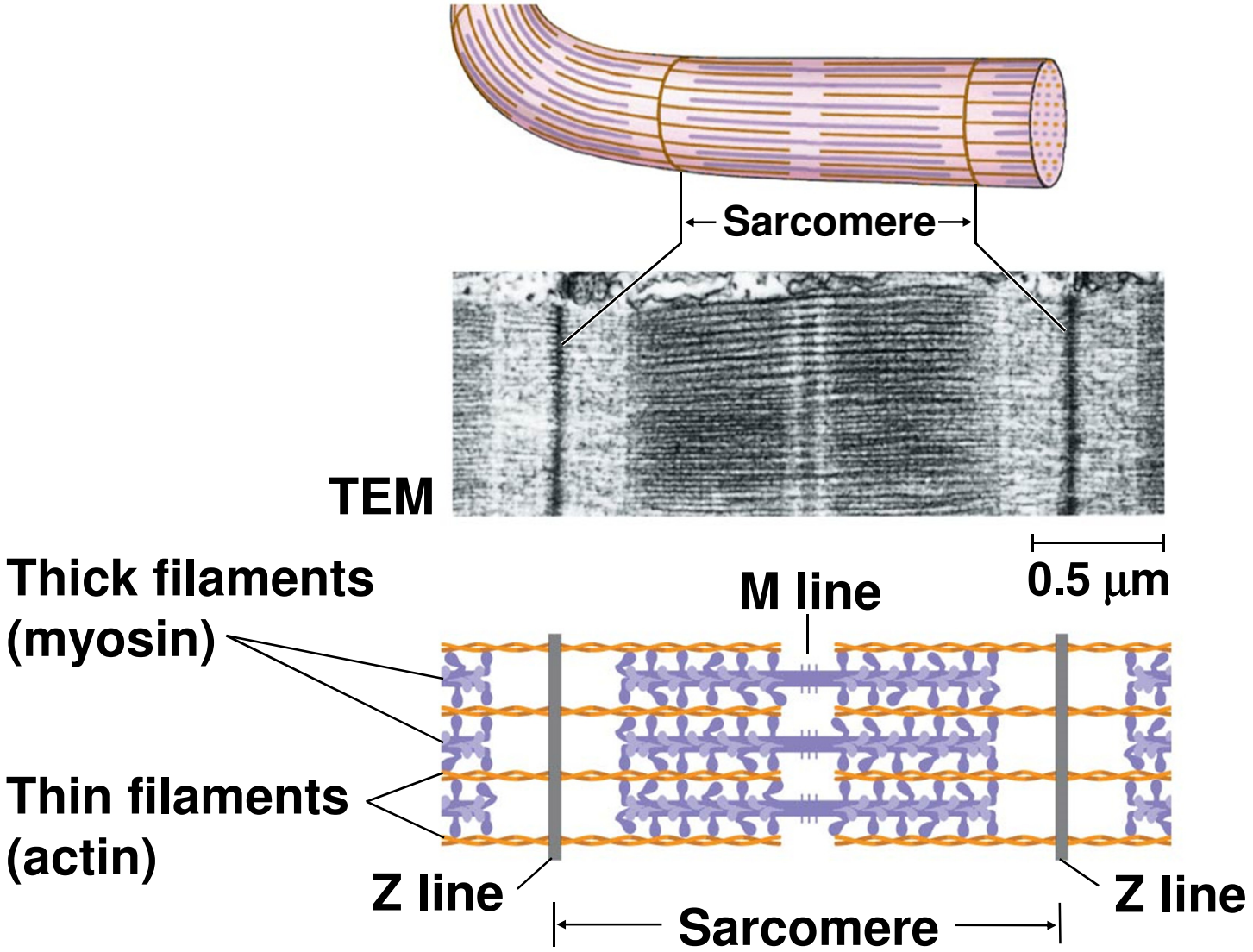
Muscles

- Muscle contraction is an active process powered by chemical energy
- Muscle relaxation is passive
- Skeletal, cardiac, and smooth muscle cell contraction all rely on the interaction between protein structures
  - **Thin filaments** consist of two strands of actin coiled around one another
  - **Thick filaments** are staggered arrays of myosin molecules

Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** moves bones and body
  - Striated
- Each muscle fiber is a bundle of smaller **myofibrils**
  - Contain thick and thin filaments
  - Made up of repeating sections called **sarcomeres**
    - Basic contractile units of skeletal muscle
- Thin filaments attach at the end of sarcomeres: Z lines
- Thick filaments are anchored in the middle: M line
- In a muscle fiber at rest, thick and thin filaments partially overlap
  - Edge only has thin actin filaments
  - Center contains only thick myosin filaments

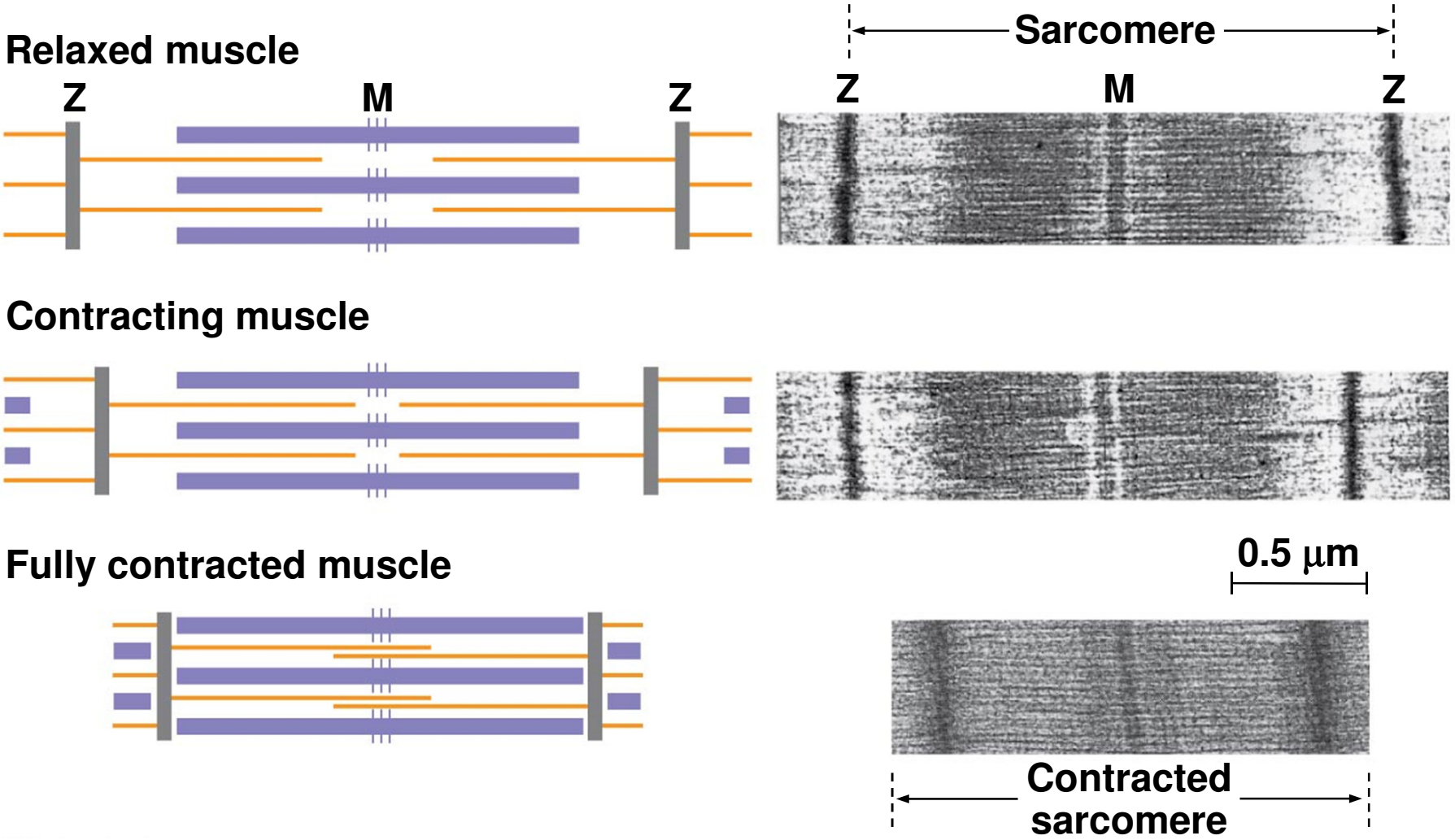
Figure 39.2b


Sarcomere
TEM
0.5 μm
Thick filaments
(myosin)
M line
Thin filaments
(actin)
Z line
Z line
Sarcomere

The Sliding-Filament Mechanism of Muscle Contraction

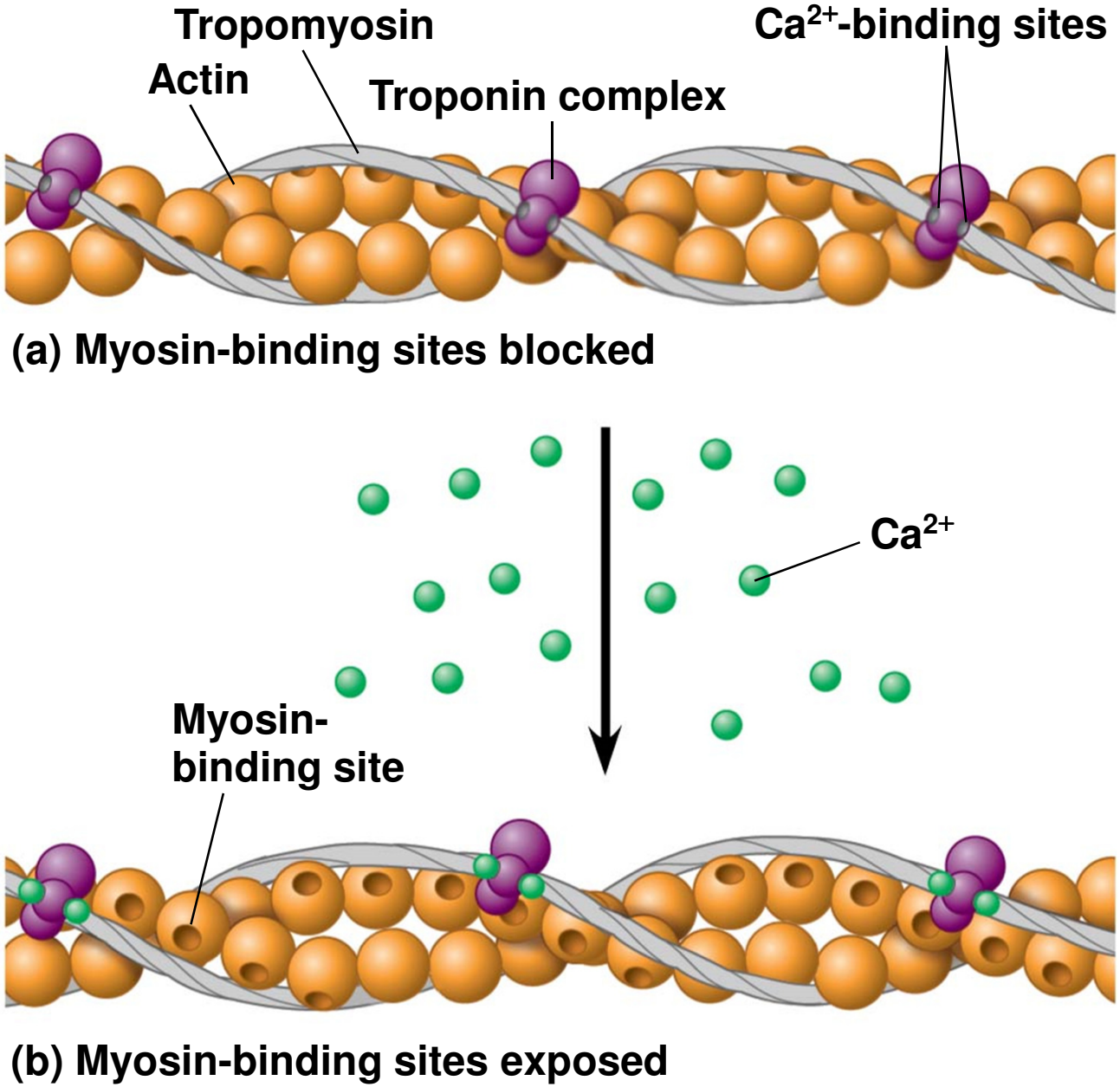
- A contracting muscle shortens
  - But the filaments stay the same length!
- According to the **sliding-filament model**, filaments slide past each other longitudinally, causing an overlap between thin and thick filaments
  - Sliding of filaments relies on interaction between actin and myosin
- The "head" of a myosin molecule binds to an actin filament, forming a cross-bridge
  - Pulls the thin filament toward center of sarcomere
- Muscle contraction requires repeated cycles of binding and release
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction

Figure 39.3


Relaxed muscle
Z
M
Z
Sarcomere
Z
M
Z
Contracting muscle
Fully contracted muscle
0.5 µm
Contracted sarcomere

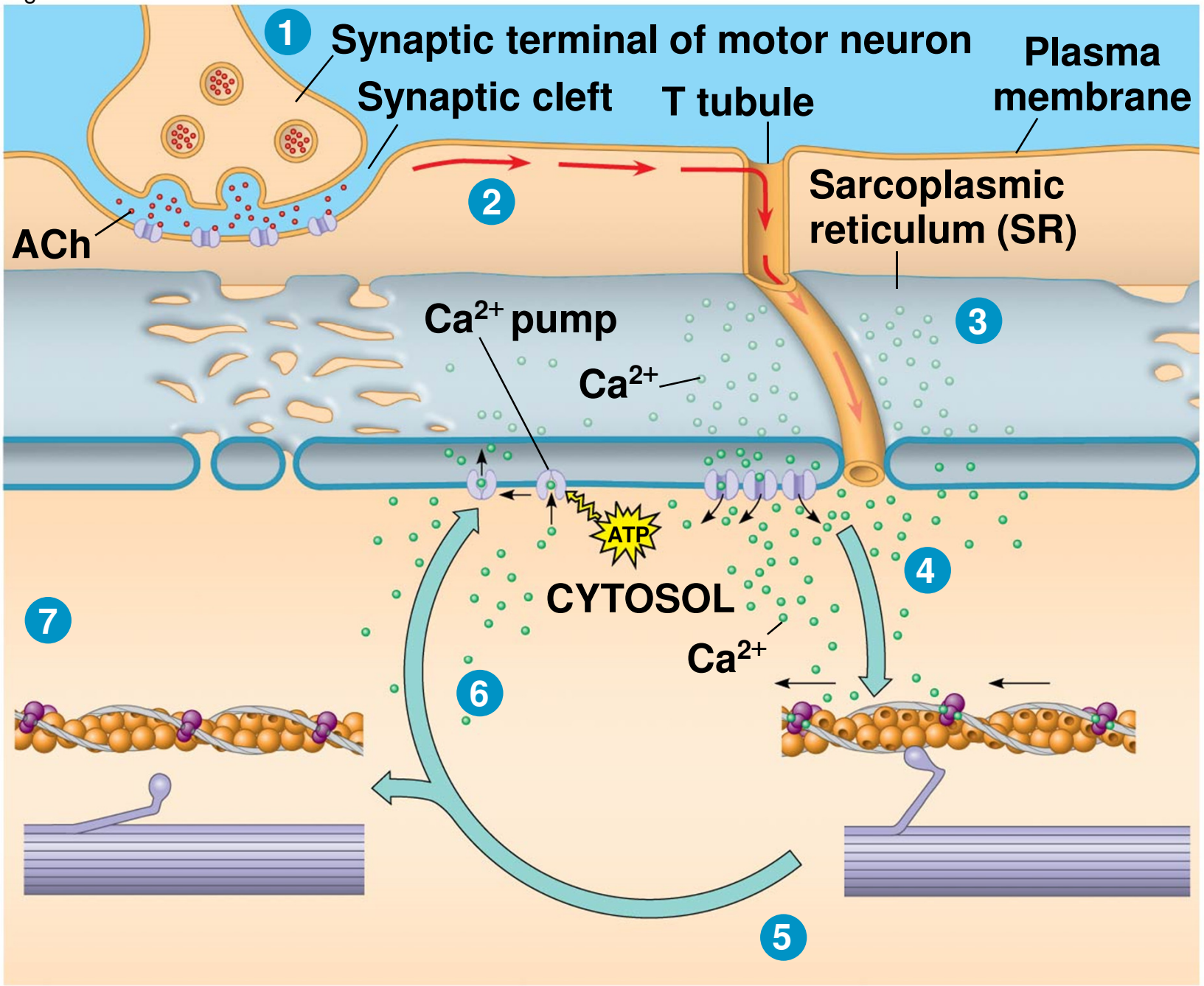
- Calcium is crucial to muscle contraction and relaxation
- **Tropomyosin** and **troponin complex** bind to actin strands on thin filaments when muscle fiber is at rest
  - Tropomyosin covers myosin-binding sites along thin filament
  - Prevents actin and myosin from interacting
- For a muscle fiber to contract, myosin-binding sites must be uncovered
  - Calcium ions bind to the troponin complex and expose the myosin-binding sites
    - High concentration of Ca^{2+} = contraction
    - Low concentration of Ca^{2+} = no contraction

Figure 39.5


Tropomyosin
Actin
Troponin complex
Ca^{2+}-binding sites
(a) Myosin-binding sites blocked
Ca^{2+}
Myosin-binding site
(b) Myosin-binding sites exposed

- In order for a muscle to contract:
  1. Action potential in motor neuron
  2. Axon releases acetylcholine
     - Depolarizes muscle
  3. Calcium released by sarcosplasmic reticulum
  4. Calcium binds to troponin, shifting tropomyosin
     - Unblocks myosin binding sites
  5. Myosin binds to actin
     - Ratchets thin filament toward center
     - Using energy from ATP

Figure 39.6b


1
Synaptic terminal of motor neuron
Synaptic cleft
T tubule
Plasma membrane
2
ACh
Sarcoplasmic reticulum (SR)
3
Ca^{2+} pump
Ca^{2+}
ATP
CYTOSOL
4
Ca^{2+}
7
6
5

Types of Skeletal Muscle Fibers

- Skeletal muscle fibers are classified by
  - The source of ATP powering the muscle activity
  - The speed of muscle contraction

	Slow Oxidative	Fast Oxidative	Fast Glycolytic
Contraction speed	[redacted]	[redacted]	[redacted]
Major ATP source	[redacted]	[redacted]	[redacted]
Rate of fatigue	[redacted]	[redacted]	[redacted]
Mitochondria	[redacted]	[redacted]	[redacted]
Myoglobin content	[redacted]	[redacted]	[redacted]

Other Types of Muscle

- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
  - All 3 have thick and thin filaments
- **Cardiac muscle** is found only in the heart
  - Striated
  - Involuntary
    - Electrically connected by gap junctions called **intercalated disks**
    - Can generate action potentials without neural input
- **Smooth muscle** is found in walls of hollow organs such as those of the digestive tract and blood vessels
  - Involuntary
    - Contractions caused by stimulation from neurons in the autonomic nervous system

Communication

- 4 common modes of animal communication:
  - Visual, chemical, tactile, auditory
- Most terrestrial animals are nocturnal
  - Visual displays are relatively ineffective
  - Rely on olfactory and auditory signals
- Diurnal animals (active during daytime) like birds
  - Communicate by visual and auditory signals
- Many animals that communicate through odors emit chemical substances called **pheromones**
  - Often relate to reproductive behavior
  - Can serve as alarm signals
- Pheromones serve in communication between animals of the same species!

Learning and Behavior

- **Innate behavior** is developmentally fixed and does not vary among individuals
  - IE-Know what to do when born
  - Examples
    - Fixed action patterns
    - Courtship stimulus-response chain
    - Pheromone signaling
- **Learning** is the modification of behavior based on specific experiences

- **Imprinting** is the establishment of a long-lasting behavioral response to a particular individual
  - Can only take place during a specific time in development, called the **sensitive period**
    - Limited developmental phase that is the only time when certain behaviors can be learned
  - Examples:
    - Young geese following their mother
    - Salmon returning to home stream to spawn
    - Goat recognizing own kid by smell

- **Spatial learning** = establishment of a memory that reflects the spatial structure of the environment
  - Ex: Digger wasps use landmarks to find nest entrances
- **Associative learning** = animals associate one feature of their environment with another
  - Ex: Associating color with foul taste
- **Social learning** = learning through observation of others (forms roots of culture)
  - Ex: Young chimpanzees learn to crack palm nuts with stones by copying older chimpanzees

- **Cognition** is a process of knowing that may include awareness, reasoning, recollection, and judgment
  - Ex: Honeybees can distinguish “same” from “different”
- **Problem solving** is the process of devising a strategy to overcome an obstacle
  - Ex: Chimpanzees can stack boxes in order to reach suspended food
  - Ex: Ravens obtained food suspended from a branch by a string by pulling up the string

Mating Behavior

- In **monogamous** relationships, one male mates with one female
  - Males and females often look similar
- In **polygamous** relationships, an individual of one sex mates with several individuals of the other sex
  - Usually exhibit *sexual dimorphism*
    - Males and females differ in appearance
  - In *polygyny*, one male mates with many females
    - Males are larger and more showy than females
  - In *polyandry*, one female mates with many males
    - Females are often more showy than males

Altruism

- Natural selection favors behavior that maximizes an individual's survival and reproduction
  - These behaviors are often selfish
- On occasion, some animals behave in ways that reduce their individual fitness but increase the fitness of others
  - Called **altruism**, or selflessness
  - Ex: Ground squirrel will make an alarm to warn others of a predator, even though the noise increases its own chances of being killed
  - Ex: Nonreproductive naked mole rats may sacrifice their lives to protect reproductive queen form predators